Industrial Waste Audit and Reduction Manual

A practical guide to conducting an in-plant survey for waste reduction

Edited by John Richmond and published by the Ontario Waste Management Corporation (OWMC) with the assistance of CANVIRO Consultants.

OWMC is a provincial Crown agency created by an act of the Ontario legislature in 1981 to establish a provincial system for treating and disposing of liquid industrial and hazardous wastes. OWMC also helps industry with waste reduction, reuse, recycling and recovery.

Ontario Waste Management Corporation

Société Ontarienne De Gestion Des Déchets

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Chapter 1: Introduction to Waste Auditing and Reduction

Chapter 1: Introduction to Waste Auditing and Reduction

What is a waste audit?

The in-plant survey or waste audit is the first step in reducing waste and overcoming pollution problems. It is a detailed analysis of your company's processes and wastes aimed at minimizing, or even eliminating, discharges from unit processes.

Carrying out a waste audit involves observing, measuring and recording process-related data, collecting and analyzing waste samples and asking questions around the plant. To be effective it must be done methodically and thoroughly under the direction of a dedicated waste reduction supervisor who has been freed from all production and administrative duties. The audit should also involve all personnel from top management to shop floor workers.

A good waste audit should:

- define sources, quantities and types of waste being generated
- bring together information on unit processes, products, raw materials, water usage and waste generation
- highlight process efficiencies and inefficiencies
- identify areas of wastage and loss and waste problems
- help set targets for waste reduction
- permit development of cost-effective waste management strategies
- increase employee knowledge of production processes and concern for waste reduction

Why reduce wastes?

The days of cheap resources, low energy costs and little environmental regulation have gone for good. Companies today are taking a closer look at how they can reduce their wastes and thereby cut their costs and comply with increasingly strict regulations.

Tighter regulations governing waste disposal, particularly Regulation 309 of Ontario's Environmental Protection Act, coupled with escalating costs, are the two greatest incentives for industry to cut down on its waste production.

The Ontario Ministry of the Environment's municipal and industrial strategy for abatement (MISA) is putting an end to one method of disposal. Limits will be placed on the total amounts of contaminants (by weight) which municipal treatment facilities and industrial generators can discharge to sewers, rivers and lakes. Municipalities not meeting these limits will be forced to either upgrade their treatment facilities or, more likely, require waste generators to reduce the amount of wastes discharged to the sewers.

Some plants are complying with these restrictions by treating the total plant effluent. This approach tends to be very costly and can be much less

effective than reducing wastes at source. End-of-pipe treatment deals with large volumes of dilute wastes which contain complex mixtures of process waste materials. The resulting treatment processes tend to be cumbersome and it is often difficult to destroy or remove a high percentage of all contaminants. A far better approach is to move back up the pipe and identify and segregate waste streams at their source for treatment or reuse.

Getting Started

It costs a company manpower and money to carry out a waste audit and therefore senior management support is essential. Obviously the reader of this manual, if he/she is a staff employee will have to present sound reasons in order to obtain such support. These could include:

- reduced waste generation
- reduced raw material consumption
- reduced waste treatment costs
- reduced potential liability
- improved public relations
- enhanced process efficiency resulting in improved company profits.

When writing to senior management for approval, be specific. Tell your supervisors where you suspect losses are occurring or where you think money can be saved. Of course the hard data you need to back up your suspicions can only be obtained by carrying out the audit, but in many cases projections can be enough to induce management to allocate the resources you need.

An audit can be successful only through employee involvement and cooperation. This means that employees must be assured the audit will be a non-blaming process and they will not be punished for poor past operating practices. If employees feel management is looking for scapegoats, they will not cooperate. It is important to tell employees why the audit is being carried out and let all concerned know the results of the audit once it has been completed. It is important to set goals; quantitative goals are preferable to qualitative ones. For instance, your company could adopt a goal of seven per cent waste reduction annually with the eventual goal of zero discharge by a specified year. Cash or other incentives for ideas resulting in improved efficiency and waste reduction could be offered to employees.

The number of people on an audit team will depend on the size and complexity of the plant. An audit team for a larger plant could consist of three or four people: an environmental specialist, a production employee and one or two technical people from a sister plant who are perhaps involved in research and development, maintenance or consulting. The size of the team is not critical. In a small plant the owner may wish to

conduct the audit by himself with input from his employees. If possible, the leader of the audit team should be freed from other duties until the audit is completed. Frequently the necessary data for an audit can be collected in two weeks. Interpretation of the results will take longer. In other cases an audit could take more time depending on a number of factors such as the size of the plant and the focus of your audit (i.e., the level of detail, the number of plant operations you wish to examine and so forth). This is all up to you.

This manual is designed to be used by staff at all levels—technical as well as non-technical. It is a practical guide to help you understand your processes. In many cases your processes generate waste as the main product, whereas finished goods to be sold are, in essence, a small by-product stream. Apply this manual to your unique situation and focus on concept rather than detail, for example, Step 5 records water usage. If you don't use much water there may be no need to spend time collecting data just to fill in Table 4. Because the manual is generic, its approach can be applied to the entire spectrum of manufacturing activities.

It is important at the outset to select a focus for your audit. For example your audit could concentrate on wastes which fit any of the following criteria:

- costly to dispose of
- generated from expensive raw materials
- present processing problems
- considered to be hazardous or regulated under pollution control legislation
- easy to reduce.

The audit should be conducted during working hours so that production processes are visible and questions can be asked of employees.

Your audit will be a snapshot in time. Processes change and your plant tomorrow will not operate in exactly the same manner as it does today. Therefore, a more realistic picture will be obtained if the audit is conducted over a period of time to average out daily input and output fluctuations. Furthermore a new audit should be performed when major changes occur at your plant such as:

- changes in the price of raw materials
- changes in regulations
- changes in the cost of disposal
- process changes.

Chapter 2:
An Approach

Chapter 2: An Approach

Overview

This chapter describes an approach to conducting your waste audit. It is designed to be generic in nature to apply to as broad a spectrum of Ontario industry as possible. As you go through the 18 steps, it may become obvious that some parts do not apply to your particular circumstances. You may also require additional or modified steps for your individual needs. If this is the case, then adapt as necessary. However, we feel that the following approach is sound and should form the basis of your investigations.

The waste audit/waste reduction approach is divided into six phases and incorporates a number of steps as follows:

Phase One: Understanding the processes in your plant

Step 1: Listing of unit processes
Step 2: Constructing a process flow diagram

Phase Two: Defining process inputs

Step 3: Determining resource usage
Step 4: Investigating raw material storage and handling losses
Step 5: Recording water usage
Step 6: Determining current levels of waste reuse

Phase Three: Defining process outputs

Step 7: Quantifying process outputs
Step 8: Accounting for wastewater flows
Step 9: Documenting wastes stored and hauled off-site for disposal

Phase Four: The material balance study

Step 10: Assembling unit process input and output information
Step 11: Deriving a preliminary material balance for unit processes
Step 12: Evaluating the material imbalance
Step 13: Refining the material balance

Phase Five: Identifying waste reduction alternatives

Step 14: Examining obvious waste reduction measures
Step 15: Targeting problem waste streams
Step 16: Developing long-term waste reduction alternatives

Phase Six: Cost/ benefit analysis and implementing action plan

Step 17: Doing a cost/benefit analysis for waste treatment/reduction
Step 18: Implementing your action plan: reducing wastes and increasing production efficiency

The following section describes the 18 steps. It should be emphasized that although the auditing procedures are described as discrete steps, the audit needs to be thoroughly planned and developed by the user into an efficient and integrated approach. For example, Phases Two and Three should be run concurrently. It may also be worthwhile to refer to the case studies while you progress through the audit.

Phase One of the waste audit involves going into the plant and developing a sound understanding of all the process components and their interrelationships. It is worthwhile at this stage to solicit help from staff who are familiar with the day-to-day operations of the plant.

Phase One: Understanding the processes in your plant

Step 1: Listing of unit processes

Your plant consists of many unit processes. The first step in the waste audit is to identify and list all your unit processes and then assemble as much information on them as possible. A unit process can be defined as an area of the plant or piece of equipment where materials go in, something happens and materials come out, possibly in a different form, state or composition. It may be grinding, painting, plating, dyeing, filtering, warehousing or your waste treatment system.

A walk through the plant will help the audit team decide how to describe plant production in terms of unit processes. During this walk through it may be very helpful to sketch a line drawing of processes, sewers, drains, vents, plumbing and other material transfer areas. By doing this you will be less likely to miss important input and output data. Part of the walk through is asking questions of foremen and operators about processing and waste generating operations such as spills, clean-ups,rinses and washes.

A plant tour may disclose that actual material handling practices are different from those in written procedures or used in the past. During the walk through note imminent problems that need to be addressed before the audit is completed.

Start the audit with something easy. The level of detail is up to you. A whole plant, a processing building, an area, one piece of equipment or an entire production line could be targeted. If you can't get all the information about a particular process without a lot of work and plumbing changes, perhaps you can get material input and output information of the building the process is located in. This level of detail may be sufficient.

Record information on unit processes in a table similar to Table 1 and begin developing a file of all existing information. For the sake of keeping records, assign a name to each unit process. Use your discretion as to the level of detail collected. It may be necessary to concentrate on certain problem areas to start with, for example, in the first case study in chapter three the complexity of the plant was such that the waste audit was carried out with specific reference to copper—the contaminant causing major problems with respect to sewer discharge compliance. However, before you decide to narrow the scope of the audit, ensure that it is done from a sound understanding of the process involved.

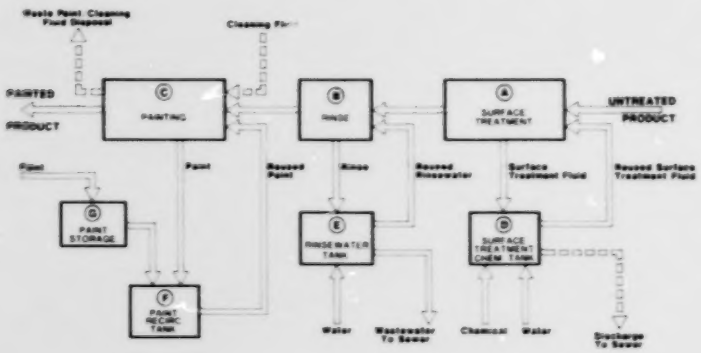
Table 1: Identification of unit processes

Unit Process	Functional Description	File Number
e.g. Surface Treatment (A)	-Surface treatment of metal products before painting -10 m^3 spray chamber -6 jets, 100 L/m pump	1
(B) etc.		2

Step 2: Constructing a process flow diagram

By interconnecting the individual unit processes in the form of a block diagram you will have prepared a process flow diagram. Intermittent operations such as cleaning, make-up, or tank dumping should also be included in the process flow diagram and can be identified by broken lines and labelling. Figure 1 is an example of a simplified process flow diagram.

Figure 1: Example of process flow diagram



With complex processes it is recommended that you not try to include every unit process in the process flow diagram. Instead, prepare a general flow diagram describing the main processing areas and on separate sheets of paper prepare detailed flow diagrams of each main processing area. Case one in chapter three shows how this can be done (Figures 1-6).

One of the most basic and widely used principles of chemical engineering is that of material balance, i.e., the total weight of what goes into a unit process must equal the total weight of what comes out. The principle of material balance is used later in the waste audit (Phase Four), but it is worthwhile considering the approach at this stage. By obtaining information on inputs and outputs, a material balance can be written around a single item of process equipment, a portion of a process, a complete

process or an entire processing plant. It is here that you have to decide on the level of detail you require. As mentioned previously, to begin with you may wish to home in on specific problem areas.

It is important to realize, however, that the less detailed the audit becomes, the more information is likely to be masked or lost. For example, in the process described in Figure 1 there are seven unit processes. It is possible to define the inputs and outputs to each unit process, but if time is limited or you consider that the storage tanks are not of specific concern, then effort could be concentrated on the major unit processes, i.e., surface treatment (A), rinsing (B), and painting (C). However, if the surface preparation, rinsing and painting operations were grouped together then information on the loss of water and surface treatment chemicals between the surface treatment stage and the rinse stage could be lost.

By measuring the volume of water and quantity of surface treatment chemicals that are carried over to the rinsing stage you can identify significant raw material losses with subsequent reduction in rinsing efficiency and contamination of the discharge to the sewer. Deciding on the level of detail and homing in on specific areas is therefore very important at an early stage.

Phase Two: Defining process inputs

In Phase Two of the waste audit the inputs need to be quantified. Step 3 deals with raw materials, chemicals and power, Step 4 with identification of raw material losses, Step 5 with water usage and Step 6 with current levels of waste reuse.

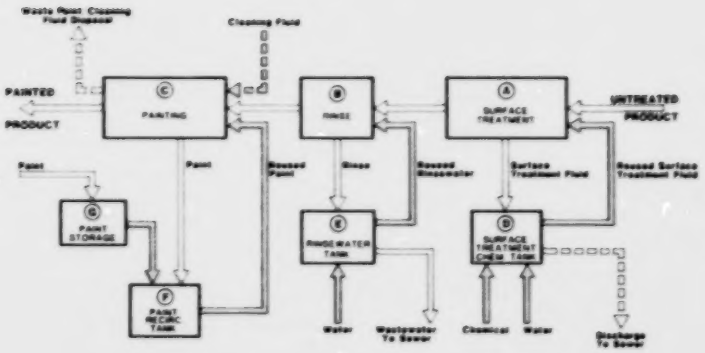


Figure 1

EXAMPLE OF PROCESS FLOW DIAGRAM

Step 3: Determining resource usage

Now that all the unit processes are designated and the interconnections are established, begin to account for material flows to each process at the detail you have decided to use. Process inputs should include raw materials, chemicals, process water, steam, and power (to be used for cost/benefit analysis). This study usually begins by examining the company purchasing records of raw materials used annually in the plant.

Assign quantities of raw materials used in each unit process. If accurate information about raw material consumption rates for individual unit processes cannot be obtained from purchasing records, then measurements will have to be made. This should be done over a sufficient period of time to smooth out fluctuations and then be extrapolated for a monthly or annual figure. Attention to detail and thoroughness is essential at the beginning of the audit to accurately assess waste reduction opportunities. Process input data should be recorded on your flow diagram or in a table like Table 2.

Table 2: Annual usage of raw materials

Unit Process	Raw Material 1 (m^3/yr)	Raw Material 2 (tonnes/yr)	Raw Material 3 (tonnes/yr)	Raw Material 4 (tonnes/yr)
Surface Treatment (A)	Water	Metal Products	Surface Treatment Chemical	-
Rinse (B)	Water	Metal Products	-	-
Painting (C)	Water	Metal Products	-	Paint
Total Raw Material Used in All Unit Processes				

Informal discussions between the waste audit supervisor and the plant operators can yield useful information about what has gone on in the past, what goes on in the present, and why certain things are being done in the plant. Furthermore, the waste audit supervisor should be familiarizing himself with the various unit processes and should be questioning and developing ideas for improvements.

Although inputs are treated separately from outputs in this manual, they occur simultaneously when your plant is operating in a steady state mode. Therefore, it is important to measure outputs to unit processes at the same time as inputs taking into consideration any significant unit process detention times. This means that the steps outlined in phase 3 need to be carried out at the same time as the steps outlined in phase 2.

Step 4: Investigating raw material storage and handling losses

Experience indicates that large amounts of waste can be generated before the actual production process begins. Often, significant quantities of raw materials are lost during storage or material handling. These losses can be quantified as the difference between the total amount of purchased material and the total used in production. You can identify these losses by developing a table like Table 3.

Table 3: Raw material storage and handling losses

Raw Material	Quantity of Raw Material Purchased (per annum)	Quantity of Raw Material Used In Production (per annum)	Type of Storage*	Average Length of Storage	Estimated Annual Raw Material Losses
Raw Material 1 (Surface treatment chemical)	100 kg	95 kg	warehouse	1 month	5 kg
Raw Material 2					
Raw Material 3					

*For example, open vs. closed.

Make notes regarding raw material storage and material handling practices. Consider such things as evaporation losses, spills, leaks from underground storage tanks, vapour losses through storage tank pressure relief vents and contamination of raw materials. Find out reasons for on-site spillage. Purchasing practices should be re-evaluated if high raw material inventories result in spoilage.

Step 5: Recording water usage

Large quantities of water are frequently used in production for cooling, gas scrubbing, clean-ups, product washing and rinsing. Record your water usages on the process flow diagram or in Table 4. Water which is not directly used in the processing operations and which is not contaminated during processing can sometimes be left out of the waste audits, although excess water use and the effect on sewer surcharges should be considered. Similarly you may wish to consider steam only when it is used in a direct (contact with fluid) fashion.

Table 4: Water usage

Water Use	Process Used	Process Reused	Cleaning Used	Cleaning Reused	Steam Used	Steam Reused	Cooling Used	Cooling Reused	Other Used	Other Reused
Unit Process A										
Unit Process B										
Unit Process C										

Used: Quantity of water used in unit process
Reused: Quantity of water recirculated
All measurements in standard units, e.g. m^3/annum

Reduction and tighter control of water use can reduce the volume of waste requiring treatment and result in overall cost savings. Attention to housekeeping practices can often reduce water usage and the amount of waste requiring treatment. The cost of storing clean-up waters for later reuse may be far less than the cost for their treatment and disposal. Countercurrent rinsing and rinsewater reuse will be highlighted in case studies one and two in Chapter 3. Water usage can be estimated through properly calibrated metering or measurement at the point of use, as necessary. Identify the number of times per day clean-up is undertaken and evaluate the appropriateness of reducing these practices. What controls are placed on indiscriminate water use?

Using less water can have even greater cost savings than the actual cost of water. By reducing the amount of water used, through devices like flow restriction valves, waste treatment systems can operate more effectively and be sized smaller. If your wastewaters are metered and your costs based on the quantity of effluent, then these costs are also reduced.

Step 6: Measuring current levels of waste reuse

Some wastes lend themselves to direct reuse in production. Other wastes may require some level of treatment or modification for reuse as a raw material. In addition, some wastes can be recycled through waste exchanges (see Chapter 4), and may even generate profits or offset costs if sold to another industry. These reused waste streams should be quantified. Estimate the annual quantity of waste reused as a production raw material and record the quantities on your process flow diagram or in Table 5.

Table 5: Annual quantity of reused wastes

Unit Process	Waste Type	Site and Quantity of Waste Reuse (m^3/annum)	Waste Type	Site and Quantity of Waste Reuse (m^3/annum)
Surface Treatment (A)	Surface Treatment Chemical	Surface Treatment Chamber 12 000 m^3/yr	-	-
Unit Process B (etc.)				
Unit Process C (etc.)				

e.g. Waste Type X could be contaminated rinsewater used as make-up in Unit Process A

The reuse of waste can be facilitated by waste segregation. Mixing waste streams often compounds treatment problems, sometimes rendering generally non-hazardous waste as hazardous, i.e. by combining a non-hazardous waste stream with a hazardous waste stream you can generate a hazardous waste stream of greater volume. Review your waste collection and storage approaches to determine if waste segregation is possible. It could be useful to overall plant production.

Phase Three: Defining process outputs

In Phase Three of the waste audit the outputs from the unit processes need to be quantified. Step 7 deals with the overall output picture. Steps 8 and 9 specify the waste-water flows and wastes hauled off-site.

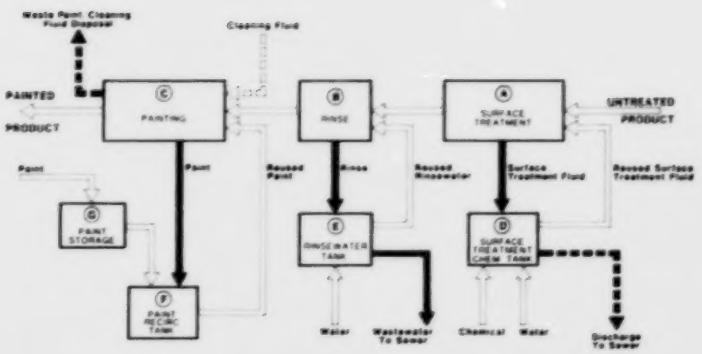


Figure 1

EXAMPLE OF PROCESS FLOW DIAGRAM

Step 7: Quantifying process outputs

The previous steps should document all process inputs as either resources (including power) or reused wastes. Now it is necessary to identify and quantify the outputs as primary products, co-products, waste to be reused and waste to be disposed of. The end product output quantities can probably be determined from company records but should also be measured. In the case of intermediary products measurements, samples and analyses will have to be made. Be sure to identify the units of measurement. Record your process outputs in your process flow diagram or in a table like Table 6. Steps 8 and 9 will assist you in assembling the output information.

Table 6: Process outputs

	Process Outputs					
Unit Process	Product A	Product B	Waste to be Reused	Wastewater to be Sewered	Waste to be Stored	Waste to be Disposed of
Unit Process A						
Unit Process B						
Unit Process C						
Total						

Note: Examples are included in Chapter 3.

Step 8: Accounting for wastewater flows and concentrations

If your plant is like many others, significant quantities of both clean and contaminated water are discharged to the sewer. This costly practice has the potential for undesirable environmental effects and could result in liability to your company. For these reasons, Step 8 is very important to the waste audit and to your company's operation.

Wastewater flows are accounted for in Step 8 along with the concentration of contaminants of concern in this wastewater. Contaminants of concern are defined by the scope of the audit. If you are an electroplater, for instance, you might wish to consider nickel and chromium as contaminants of concern in order to determine how much money is being lost when they are discharged to the sewer or trucked to disposal. A substance is definitely a contaminant of concern if it is being discharged in concentrations exceeding regulatory limits. If you do not have in-house analytical facilities, reputable contract laboratories should be contacted for this purpose.

Plan your sampling program thoroughly and try to take samples over a range of plant operating conditions, e.g. full production, start-up, shut-down and clean-up. The program to collect data should be carried on until there is enough information to allow you to assess existing conditions.

Composite samples should be taken for continuously running wastewater streams (i.e. collection of a small volume, say 100 mL, every hour through a production period, say 10 hours, to get a litre composite sample). The composite sample represents the average wastewater conditions in that timespan. For batch tanks and periodic dumping, a single grab sample may be adequate although periodic sampling of one batch and from batch to batch can highlight operating variations.

Advice on sampling techniques can be obtained from OWMC, environmental consultants or a contract laboratory. The sum of the wastewaters generated from each unit process (sewered, stored, reused, discharged to the atmosphere and disposed of at an off-site facility) should closely approximate the amount of water metered into the plant. It should be noted that "double counting" can occur where wastewater is reused. This emphasizes the importance of understanding your processes and their interrelationships. Record wastewater flows and concentrations of contaminants of concern to you in your process diagram or in a table like Table 7.

Table 7: Wastewater flows

Source of Wastewater	Discharge to											
	Sanitary Sewers		Stormwater		Watercourse		Reuse		Storage		Total Wastewater Output	
	Flow	Conc'n	Flow	Conc'n	Flow	Conc'n	Flow	Conc'n	Flow	Conc'n	Flow	Conc'n
Unit Process A												
Unit Process B												
Unit Process C												

Flows in m^3/d Concentrations of contaminants of concern in mg/L

Measuring wastewater flows can be relatively simple if your system is metered. However, ensure your meters are accurate and implement a regular calibration check to maintain accuracy. If your flows are not metered then measure flows manually or analyze pumping times and rates. Record these measurements over a sufficiently long period of time and update regularly. One factor that is often overlooked is the use of several discharge points. It is important to identify the location, type and size of all discharge flows. Determine where the discharge usually goes (i.e. sanitary or storm sewer or direct discharge to a watercourse). For this purpose it could be very beneficial to construct a process flow sheet to relate the layout of the process drains and their interconnections. This type of evaluation has often led to startling discoveries about how much waste is inadequately managed.

Step 9: Documenting wastes stored and hauled off-site for disposal

Measure the quantity of sludge or liquid waste hauled off-site for treatment and/or disposal and record these quantities, and the concentrations of contaminants of concern, on your process flow diagram and/or in Table 8. The MOE manifest records may be useful here if the waste is defined as a "registerable industrial waste" or a "hazardous waste". According to Regulation 309, all waste generators in Ontario are required to register with the MOE the types and quantities of liquid industrial and hazardous (solid and liquid) wastes they produce at their facilities. Each time a shipment of these wastes is hauled off-site, a manifest form must be written up according to MOE requirements. The waste generator keeps one copy of these manifests and from these it is possible to calculate the quantities of hazardous waste generated.

Table 8: Quantities of wastes hauled off-site for disposal
(Similar table for quantities of wastes stored on-site)

	Non-Registerable Wastes					Registerable Wastes				
	Solids			Liquids		Solids			Liquids	
Waste	Qty	Conc'n of Cont. #1	Conc'n of Cont. #2	Qty	Conc'n of Cont. #3	Qty	Conc'n of Cont. #4	Conc'n of Cont. #5	Qty	Con'n of Cont. #6
Waste A										
Waste B										
Waste C										

All quantities in tonnes/annum
Concentrations of contaminants of concern in grams contaminant/kg waste or in mg/L

We have now investigated and described what goes into the production processes and what has come out of these processes. As described earlier, one of the basic laws of chemical engineering is that the total of what goes into a system must equal the total of what comes out. Therefore, the next stage is to compare the inputs to your production process with the outputs.

When totalling these wastes, take a look at whether any hazardous and non-hazardous waste streams are combined. Review invoices for non-registerable wastes that are hauled by a commercial contractor. Again, take samples of your wastes that are hauled away and conduct analyses to determine the wastes' constituents.

Phase Four: The material balance study

This procedure is designed to identify areas where information is inaccurate or lacking. For example, if the total input to a given process for material X is 100 kg and only 50 kg is accounted for in the process output, either the output or the input data are inaccurate or the output data are incomplete. This approach is termed the material balance investigation. Where data are deficient, concentrated efforts are required. Keep in mind that it could take a long time before *all* raw material and waste flows are

accounted for. The waste audit essentially never stops, and there is usually room for improvement. Furthermore it must be emphasized that it will be almost impossible to derive a perfect mass balance—a balance to within 10 percent (e.g. Inputs/Outputs x 100 = 90 - 110%) would be deemed very satisfactory in most industrial circumstances.

Step 10: Assembling unit process input and output information

Begin the material balance by developing standard units of measurement (litres, tonnes or kilograms) on a per day, per year or per batch basis. This is the only practical way that a balance for the whole plant, or a unit process, can be carried out.

Summarize the measured values in standard units in schematic form by utilizing your process flow diagram (Figure 1). Note: modifications might be needed to Figure 1 following your work in the plant. The inputs and outputs can also be listed in tabular form as in Table 9.

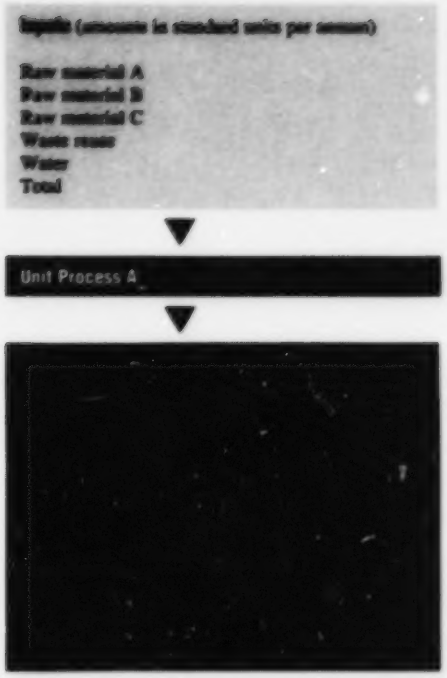
Table 9: Inputs and outputs of unit processes

Unit Process A	
Inputs	**(amounts in standard units per annum)**
Raw material A	
Raw material B	
Raw material C	
Waste reuse	
Water	
Manufactured product	
Raw material handling and storage losses	
Reused waste	
Atmospheric emissions	
Sewered waste (excluding water)	
Non-hazardous liquid waste D hauled off-site	
Hazardous liquid waste E hauled off-site	
Non-hazardous solid waste F hauled off-site	
Hazardous solid waste G hauled off-site	
Water	

Step 11: Deriving a preliminary material balance for unit processes

Now it is possible to complete a preliminary material balance. For each unit process utilize the data developed in Steps 1 through 9 and construct your material balance. Use the process flow diagram to construct a graphical material balance. You might also find it useful to tabulate your input and output information as in Figure 2.

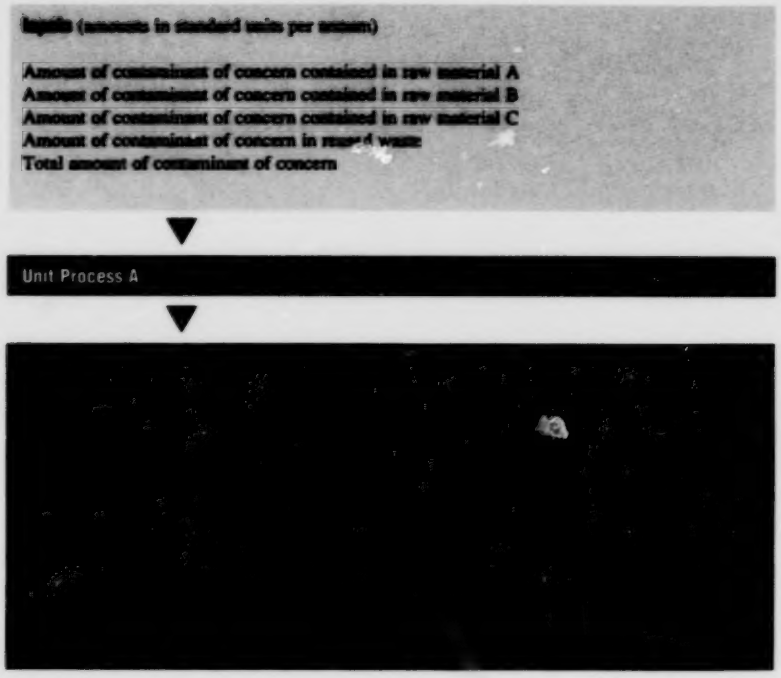
Figure 2: Preliminary material balance for unit processes



Once the material balance for each unit process has been completed for raw material inputs and waste outputs it might be worthwhile to repeat them with respect to each contaminant of concern as in Figure 3. Figure 3 might have to be modified in the event that a contaminant of concern is emitted to the atmosphere, or if one is formed as a result of a chemical reaction in the unit process.

It is highly desirable to carry out a water balance to account for all water inputs and outputs to and from unit processes because water imbalances could indicate serious underlying process problems such as leaks or spills.

Figure 3: Preliminary material balance for a contaminant of concern in Unit process A


Amount of contaminant of concern contained in raw material A
Amount of contaminant of concern contained in raw material B
Amount of contaminant of concern contained in raw material C
Amount of contaminant of concern in
Total amount of contaminant of concern
Unit Process A

Step 12: Evaluating the material imbalance

Whether you have a material imbalance or not, the individual and sum totals making up the material balance should be reviewed to determine information gaps or inaccuracies. If you do have a significant material imbalance then further investigation is needed. For example, if outputs are less than inputs, then look for obvious sources of loss or waste discharges (e.g. evaporation).

It is also possible for outputs to apparently be greater than inputs if large measurement or estimating errors are made or some inputs are not accounted for. You should now take the time to examine where unnoticed losses may be occurring, even if the equation appears to balance. It might be necessary to repeat some of your information gathering activities. Remember that you need to be thorough and consistent in order to obtain a satisfactory material balance. The material balance not only reflects the adequacy of your data collection activities, but by its very nature ensures that you have a sound understanding of the processes involved.

Step 13: Refining the material balance

Now you can reconsider the material balance equation by adding previously unaccounted for losses into the output side and any adjustments to the total inputs, and run through another material balance. If necessary, estimates of unaccounted for losses will have to be calculated. Remember,

ideally the inputs should equal the outputs. In practice, however, this will rarely be the case and some judgement will be required to determine what accuracy is acceptable. In the case of high strength and hazardous wastes accurate measurements should be obtained for the waste reduction studies.

The material balance approach should be performed at the level of detail you decided to conduct the study. You may need to repeat the material balance for a number of the unit processes identified in Steps 1 to 9 as well as an entire production area. Again, continually review, refine and, where necessary, expand your database. The compilation of accurate, comprehensive data is essential to your successful waste audit and subsequent waste reduction.

Phases 1 to 4 have been involved with developing the waste audit for your plant. Phase 5 now looks at using the information obtained to identify waste reduction alternatives.

Phase Five: Identifying waste reduction alternatives

Step 14: Examining obvious waste reduction measures

Now that your waste audit has been essentially completed, it is time to look into implementing waste reduction measures which probably became obvious during the studies. You should adopt and maintain a definite waste prevention program by developing a code of good operating practice. For example:

- Plug leaks and fit flow restrictors to try to reduce water consumption.
- Implement a thorough and satisfactory maintenance program to prevent leaks.
- Install level controls to prevent overflows.
- Attempt to reuse washwaters and rinsewaters.
- Install adequate storage capacity to prevent overflows.
- Install tanks to hold wastewaters for reuse.
- Install tanks that are, or can be, pitched and elevated from the floor and that have well rounded corners for ease of drainage and rinsing.
- Determine whether or not your wastes can be separated "clean" from "dirty" or "aqueous" from "organic". If this is done, then concentrate on material recovery from the "dirty" wastewater.
- Find out if hazardous wastes can be segregated from non-hazardous wastes and implement segregation where possible.
- Find out if solid wastes can be segregated from aqueous waste streams and implement segregation where possible.
- Consider reusing scraps of material.
- Study your plant processes and review the potential for low waste technologies.
- List your wastes in the Canadian Waste Materials Exchange Bulletin. Other plants might be able to recycle your wastes in their processes.

Step 15: Targeting and characterizing problem waste streams

Having gone through Steps 1 to 14, you should have identified all your problem areas and have begun to consider them for waste reduction, reuse, recycling and recovery (the 4R's). Obvious waste reduction measures were identified in step 14. However, you may find it necessary to focus attention on "problem" waste streams that are:

- costly to dispose of
- generated from expensive raw materials
- causing treatment problems
- classified as hazardous under government regulations.

Even though wastes were analyzed for contaminants of concern in Steps 8 and 9, additional sampling and characterization of your wastes might be necessary for problem streams that are difficult to reduce, reuse, recycle, recover or treat. One example of a "problem" waste is described in case study 1. In this instance a detailed characterization determined the presence of chelating agents in a copper containing wastewater. These agents prevented copper removal by conventional metal hydroxide precipitation. The study concluded that an ion-exchange/electrolytic recovery system was needed to treat this wastewater.

Another company decided to undertake a detailed characterization of its wastes when it had problems disposing of spent pickle liquor. After taking a closer look into the issue, the company opted to crystallize the iron sulfate out of solution (for sale) and recycle the residual pickle liquor by adding fresh acid. This solution is highlighted in case study 2.

Treatability studies determine optimum treatment requirements and can help you improve your present treatment method. Some water treatment chemical suppliers and environmental consultants can do treatability testing for you and there are some equipment suppliers who can run laboratory and pilot tests to determine optimum conditions for treatment and recovery. The resources and information in Chapter 4 describe additional options that are available.

Step 16: Developing long term waste reduction alternatives

Longer term waste reduction alternatives will require the evaluation of potential process/production changes, waste recovery and reuse, and treatment technologies. Potential process/production changes which may

increase production efficiency and reduce waste generation include:

- continuous versus batch production
- process retention times, temperatures, agitation, pressure, catalysts, etc.
- use of dispersants in place of organic solvents where appropriate
- reduction in the quantity or type of raw materials used in production
- raw material substitution through the use of wastes as raw materials and the use of different raw materials associated with either less waste generation or the generation of less hazardous materials.

Waste reuse can often be implemented if materials of sufficient purity can be concentrated or purified. Technologies such as reverse osmosis, ultrafiltration, electrodialysis, distillation, electrolysis and ion exchange may enable materials to be reused and reduce or eliminate the need for waste treatment.

Where waste treatment is necessary, a variety of technologies should also be considered. These include physical, chemical and biological treatment processes. In some cases the treatment method can also recover valuable materials for reuse. Chapter 4 describes how you can get further technical information relating to recovery, reuse, waste treatment and associated technologies. Once the potential opportunities for waste recovery and reuse have been identified, the smaller company may wish to bring in a reputable environmental consultant with the technical expertise to evaluate the various technologies.

Phase Six: Cost/ benefit analysis and implementing action plan

Step 17: Doing a cost/benefit analysis for waste treatment/reduction

From Step 16, a number of waste treatment/recovery alternatives have been identified which may have widely differing effects on your processing plant. Long term waste treatment/reuse alternatives may include:

- process related changes (e.g. acid recovery for steel pickling)
- technology for treating and recycling specific waste streams (e.g. ion exchange or electrolytic metal recovery)
- implementation of technology for end-of-pipe treatment (e.g. biological treatment of combined chemical wastewaters)

Although these cases represent different circumstances, the general procedure for conducting the cost/benefit analysis is the same and involves a current waste treatment cost analysis, projected alternative waste treatment cost analysis and finally a cost/benefit comparison.
The approach described below is, of necessity, fairly simplistic as different companies have different methods of conducting their cost evaluations.

a) Present waste treatment cost analysis

The annual operating costs for the existing treatment system can be evaluated as in Table 10.

Table 10: Present waste treatment operating costs

Item	Annual Cost ($)
Raw material A (e.g. lime)	_____
Raw material B (e.g. polymer)	_____
Sewer (surcharge and fees)	_____
Electricity	_____
Off-site disposal	_____
Water	_____
Labour	_____
Maintenance	_____
Administrative cost (e.g. supervision, regulatory response)	_____
Total Annual Waste Treatment Cost*	_____

*For the treatment of a specific waste stream (from Process A), the bottom line would relate to the total annual waste treatment cost for Process A, whereas for an end-of-pipe treatment it would relate to all process waste treatment costs.

If there are any monetary benefits from your waste treatment (e.g. reused or recycled materials), then these should be subtracted from the total waste treatment cost.

Total Annual Net Cost Of Current Waste Treatment Process	=	Total Sum of Operating And Maintenance Waste Treatment Costs	—	Total Waste Treatment Benefits

b) Determination of cost (and benefits) of each alternative waste treatment technology

The operating costs of each waste treatment alternative is then determined using a table like Table 11 below.

Table 11: Annual operating and maintenance costs for an alternative treatment technology

Item	Annual Cost ($)
Raw material A used in alternative waste treatment	_____
Raw material B used in alternative waste treatment	_____
Sewer discharge	_____
Electricity	_____
Off-site	_____
Water costs	_____
Labour	_____
Maintenance	_____
Total Annual Operating Costs of Alternative Treatment Technology	_____

Information for the costing study can be obtained from the equipment suppliers and possibly from reference material (see Chapter 4).
If there are any monetary benefits from the alternative waste treatment processes these are also subtracted from the total operating cost as below:

Net Total Annual Operating Cost of Alternative Waste-Water Treatment Technology	=	Total Annual Operating Cost of Alternative Waste Treatment	—	Annual Waste Treatment Monetary Benefit

c) Cost/benefit comparison of current and alternative treatment technologies

In cases where the total annual operating cost of an alternative treatment technology is lower than the total annual operating cost of the current waste treatment, a study should be undertaken to determine whether this net benefit is sufficient to pay for the cost of purchasing and installing the alternative treatment technology. Each company has its own method of conducting this evaluation. Discounted cash flow analysis is one commonly used method.
The cost/benefit approach used in the above items to evaluate alternative treatment technologies is based solely on economics. While the economic factor is generally the main motivation for companies to adopt waste reduction alternatives, there are cases in which other factors can override short-term economic costs associated with waste reduction. For example, infringements of environmental or occupational health regulations could result in heavy fines or even in a court injunction to shut down the polluting company.

Sometimes the benefits are intangible, such as creating a cleaner, healthier workplace with increased employee morale and reduced absenteeism. The public relations value of implementing waste reduction measures likewise should not be overlooked. It could also turn out that the alternative waste reduction technology will simultaneously improve the quality of the final product and result in increased sales. The fact that such intangible benefits are difficult to quantify from a monetary point of view does not diminish their contribution to the overall success of your operation.

The case studies in Chapter 3 give different examples of cost/benefit analyses.

Step 18: Implementing your action plan: reducing wastes and increasing production efficiency

It takes time for plant personnel to feel comfortable with a new way of thinking. Therefore it is a good idea to implement waste reduction approaches slowly but consistently to allow everyone time to adapt to these changes.

Costs associated with waste management should be charged to the production units generating these wastes. This will encourage production to reduce their operating costs by adopting waste reduction alternatives.

You have now completed the important first steps in the waste audit/waste reduction study and have amassed a wealth of information and no doubt increased your knowledge of the plant. It is now time to review what has been done and to develop an action plan for the future. To get ready, answer the following questions:

- Did the exercise highlight areas of inefficiency and enable you to improve production efficiency and waste management approaches and costs? Quantify your successes.

- Is outside expertise or additional manpower required to complete the audit or undertake further work? If so, consult Chapter 4 or enquire about reputable consulting services.

- Are the costs of implementation too high? If so, consult the sources of public funding discussed in Chapter 4. Can implementation be done in stages?

- Have you highlighted significant information gaps or inconsistencies? If so, concentrate on these areas and explore ways and means of developing these additional data. Is outside expertise required? Again, see Chapter 4.

- Discuss your approach and solicit ideas from other staff. Utilize in-house expertise first.

- Attempt to develop a specific waste audit/waste reduction approach for your plant. Discuss this approach with similar industry people who may have undertaken a plant waste assessment or are about to do so.

- Consider all possible resources. If you are looking for further information, call the Waste Reduction Program at the Ontario Waste Management Corporation (416) 923-2918 or 1-800-268-1179 (toll free).

Chapter 3: Case Studies

Chapter 3: Case Studies

In this chapter the application of the waste audit/waste reduction approach is described in three case studies. Each of these studies has been developed from different examples of industrial waste reduction in Ontario.

Case study 1: Printed circuit board manufacturing

Company A manufactures double sided and multi-layered circuit boards for the telecommunications and computer markets in North America and Europe. The manufacturing of printed circuit boards involves a complex series of physical and chemical processing stages and as a result the wastewaters which are generated are complex, of variable composition and difficult to treat. To compound the treatment problems, many of the processing solutions contain proprietary chemicals whose composition is not available.

The main pollutants in printed circuit board manufacturing wastewaters are heavy metals, particularly copper. Company A's wastewater effluent frequently exceeds the local municipality by-laws which control discharges to the municipal sewer system. Although the company has implemented some improvements to its wastewater treatment system in recent years, discharges in excess of the by-law of 5 mg/L of copper continued to occur in 1987 and the municipality eventually decided to take legal action against Company A for persistent violation of discharge standards.

In response to these problems, the company decided to conduct a waste audit, using the Waste Audit and Reduction Manual, in order to:

- identify the sources of contamination
- develop a waste reduction strategy to minimize contaminants at source
- develop a sound understanding of the wastewater problems to facilitate the design of a cost-effective wastewater treatment system

Because of the complexity of the printed circuit board manufacturing plant it is worthwhile at this stage to give a brief description of the major processing steps. The board material is composed of a glass fibre sheet with copper laminated on both sides. The uncut boards are received from the suppliers in large sheets and pass through a shearing stage to cut them to the desired size. The boards are then drilled and pass through a surface conditioning stage (deburring) before undergoing a series of treatments in the sensitizing area (electroless plating). This treatment essentially coats copper into the holes and prepares the holes for electroplating.

The next stage involves the application of a photopolymer resist material which masks off areas which do not need to be electroplated. The printed circuit areas are subsequently developed (to remove unexposed resist areas which are to be plated) and pass through microetching, copper electroplating, solder electroplating, resist stripping, copper etching and a number of other selected finishing treatments as specified by the customer. The final stages of manufacture involve final fabrication and electrical testing.

It can be seen that the printed circuit board manufacturing plant is complex and a great number of different process wastes are thereby generated. The following case study describes the approach taken to overcome the

long-standing waste treatment problems encountered by Company A. The investigations were based on the Waste Audit and Reduction Manual and the studies highlighted a number of areas where processing and treatment efficiencies could be improved.

Phase One: Understanding the processes in your plant

Step 1: Listing of unit processes

Step 1 of the waste audit involved walking around the entire printed circuit board manufacturing plant in order to gain a sound understanding of all the processing operations and their interrelationships. It was important from the outset to determine what level of detail was required for the study. Due to the complex nature of the printed circuit board plant it was not considered appropriate to list all the unit processes in fine detail. Instead, the plant was broken up into processing areas. Furthermore, as copper was by far the major contaminant of concern, it was decided at this stage to conduct the waste audit with specific reference to copper.

Figure 1 shows the general schematic process flow diagram which was constructed from the initial plant investigations. By studying the processing operations, asking questions around the plant and assembling supplier information on chemicals and processes it was possible to identify the areas in the plant where waste copper was generated. These areas were the:

- deburring operation (sensitizing)
- sensitizing line (electroless plating)
- electroplating line (copper electroplating, solder electroplating, moist strip and copper etch)
- oxide coating area (including oxide deburring, oxide coating, solder stripping and lacquer finishing)

It is important to note that copper was not considered in isolation and that factors which could affect the form and ultimate treatability of copper were also considered (e.g. presence of chelating agents).

Step 2: Constructing process flow diagrams

Once the main processing areas which generated waste copper had been identified the process flow diagrams were constructed for each area. This involved a more detailed study of each processing area and the identification of process inputs and outputs. In addition to the four processing areas mentioned, a process flow diagram of the existing wastewater treatment plant was also developed. Figures 2-6 show the process flow diagrams for these main processing areas. It should be noted that some diagrams are simplified for the purposes of the case study.

Figure 1: General flow diagram for the printed circuit board manufacturing plant

Figure 2: Process flow diagram for sensitizing deburrer

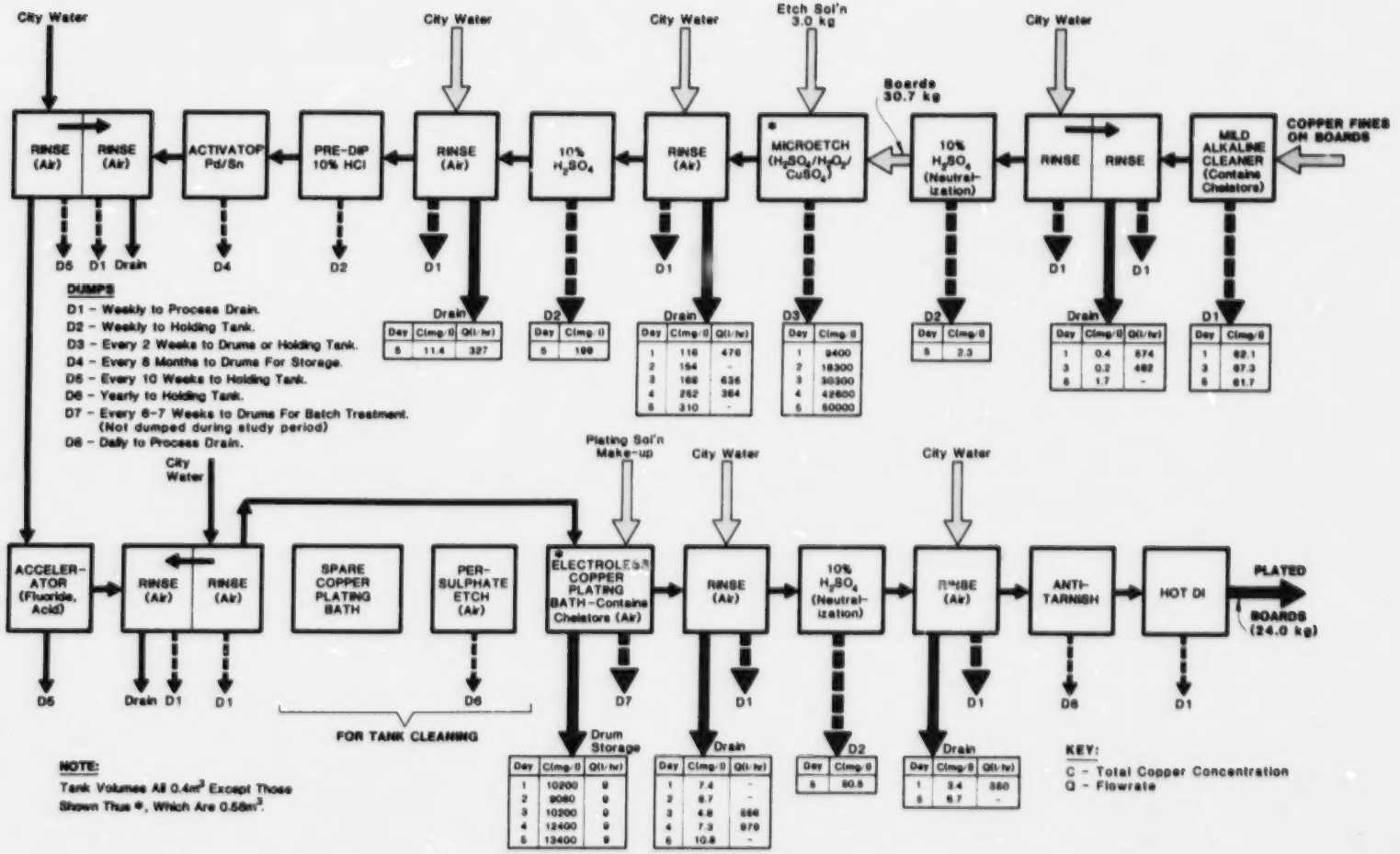


Figure 3: Process flow diagram for sensitizing (electroless plating) area

Figure 4: Process flow diagram for 9000 line (Cu electroplating Sn/Pb electroplating, resist strip and etching)

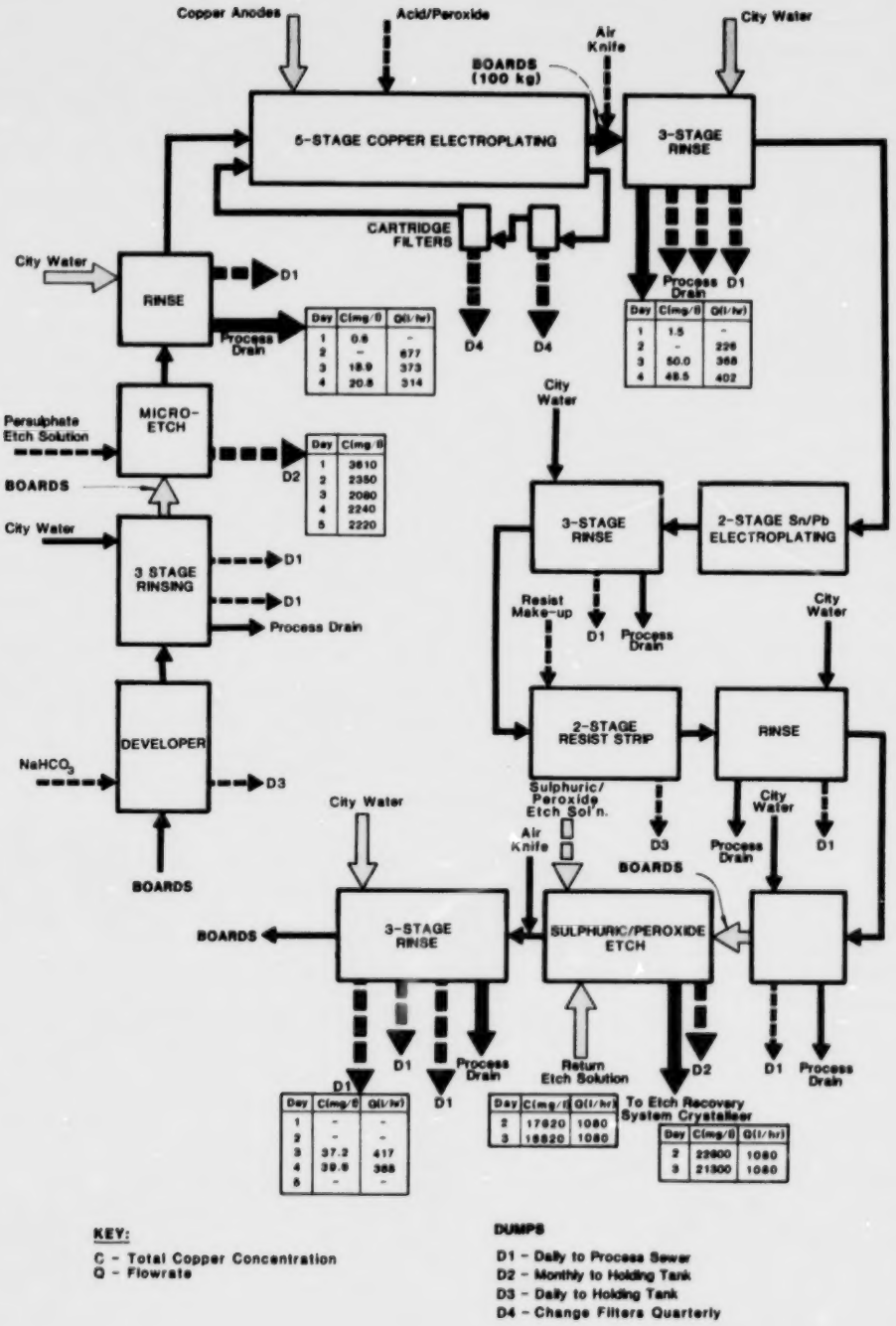


Figure 5: Process flow diagram for oxide coating, lacquer finish and tin/lead strip

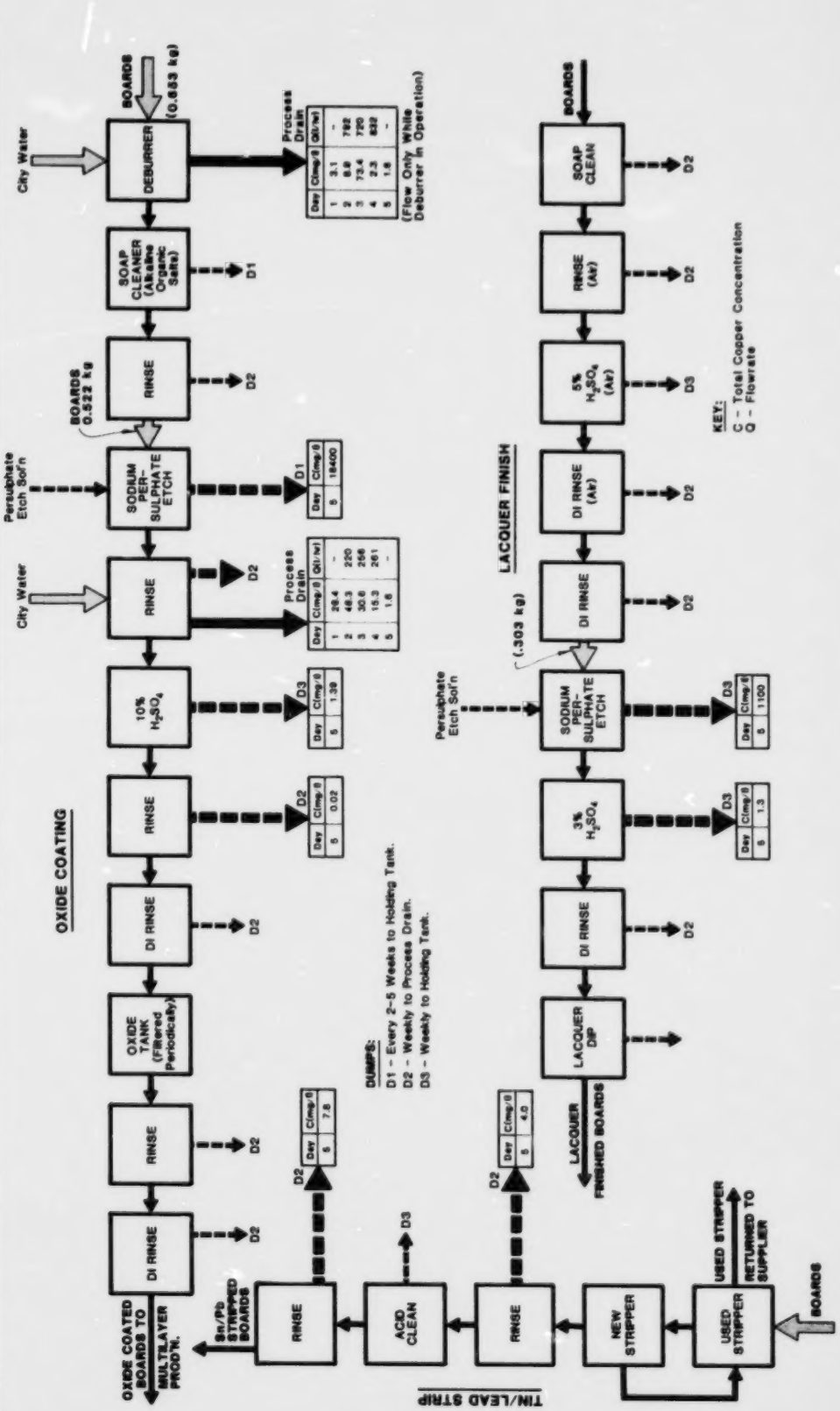


Figure 6: Process flow diagram for wastewater treatment plant

In Phase One the processes which involved copper were identified and the interconnections between these processes established. In Phases Two and Three the material flows to and from these processes need to be determined by collecting input and output information.

Phase Two: Defining process inputs

Due to the relative complexity of the printed circuit board plant the inputs and outputs for the unit operations were recorded on the process flow diagrams using Steps 3-5 of the waste audit manual. It should be emphasized that the input and output information was collected in the plant at the same time even though the auditing procedures are described in the manual as discrete steps.

While conducting the in-plant survey and collecting the input and output information the investigating team were noting any areas of inefficient operation and any opportunities for waste reduction. These opportunities are discussed later in Phase Five.

Step 3: Determining resource usage

Input information was obtained from measuring chemical additions and water use and recording the area of copper circuit boards processed (etched*). In the case of the electroplating line the weight of copper anode used (the source of copper for electroplating) was estimated from past data. The wastewater treatment plant inputs were determined by measuring the total wastewater flows and concentrations.

*Etching of the copper circuit boards involves acid treatment for surface conditioning, or finishing, and represents a significant copper input.

Copper input information for the five processing areas was then recorded on the process flow diagrams in Figures 2-6.

Step 4: Investigating raw material storage and handling losses

Due to the nature of the copper raw materials (copper sulphate solutions and copper laminated boards) no handling losses were considered to occur prior to the processing operations.

Step 5: Recording water usage

The rinsewater flowrates were measured at the inlet to the rinse tanks by measuring the time to fill a known volume container or by draining down the rinse tanks and measuring the time to refill. Company A had recently installed flow restrictors on the rinsewater feed pipes, a good water conservation measure, in order to limit the amount of water being used in the rinsing operations. In general, the flowrates measured were in accordance with the ratings for the flow restrictors.

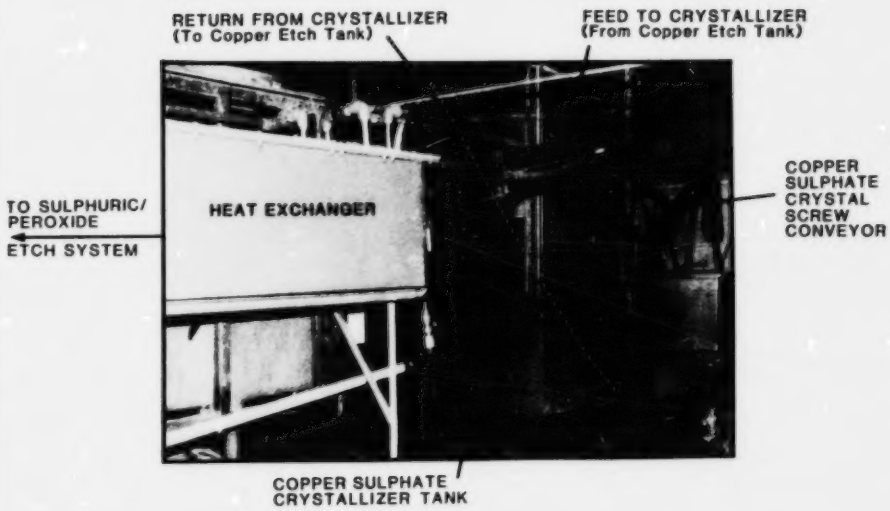
The water usage data was also recorded on the process flow diagrams (Figures 3-6).

Step 6: Measuring current levels of waste reuse

Copper-containing wastes were not generally reused at the plant. However, there was an on-line crystallizer on the sulphuric/peroxide etch stage of the electroplating line. The following photo shows the copper sulphate

crystallizer and etch solution recovery system. The etch solution is pumped from the etch tank through the heat exchanger and into the copper sulphate crystallizer where the spent etch solution is cooled to 16°C. Copper sulphate crystals are precipitated and then conveyed to the storage bins, drained and subsequently sold to a local plating shop. The recovered etch solution is returned to the etch feed tank. The quantity of etchant reused is described as an input in Figure 4.

Photo: Etch solution recovery and copper crystallization system



Phase Three: Defining process outputs

Step 7: Quantifying process outputs

The copper related process outputs were identified and then quantified from copper plating records and the measurement of waste masses, volumes and concentrations. Apart from the quantity of copper plated onto the printed circuit boards, which was determined from production information and plating thickness used, the process output information was obtained from measurements taken in the plant.

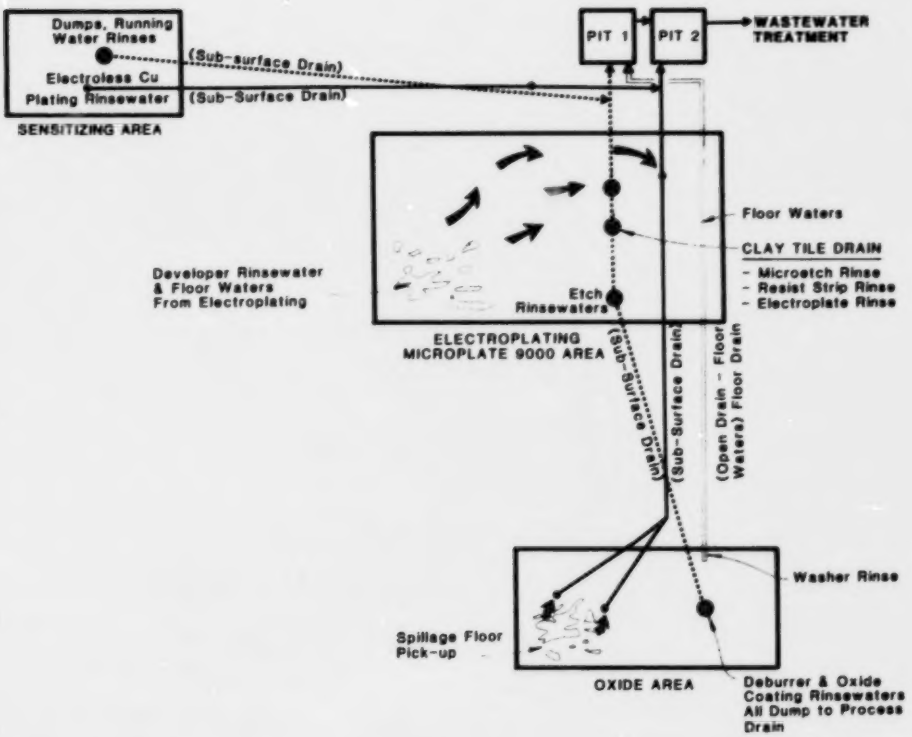
Step 8: Accounting for wastewater flows and concentrations

All the wastewater streams which were identified as containing copper (from Steps 1 and 7) were investigated in a thoroughly planned and conceived sampling programme. The sampling was performed over a production week in order to cover the full range of operating conditions and to

ensure representative data. Composite samples were taken for all running wastewater streams whereas batch tanks and dumpings were sampled with a grab method. Samples were also taken from the outputs from the wastewater treatment plant. The samples were carefully labelled, logged and sent out to a contract laboratory for copper and supporting analyses. Wastewater flows and tank volumes were also recorded. The wastewater information is described in Figures 2-6.

In addition, a process flow diagram describing the layout of the process drains was constructed (Figure 7). Dye tests were performed to determine the fate of the wastewater streams and the layout and interconnections of the surface drains. These studies highlighted some unnecessary and complex rinsewater piping arrangements which were subsequently modified by plant engineering staff.

Figure 7: Layout of process drains



Step 9: Documenting wastes stored or hauled off-site for disposal

The quantity of waste material stored on-site and hauled off-site for disposal was estimated from in-plant investigations and study of company records. The registerable wastes hauled off-site for disposal included: copper fines (270 g/100 m^2 of board), cartridge filters, and filter press cake (1360 kg/week). The tin lead activator dump (0.7 m^3/annum) was stored on-site as registerable liquid waste.

Phase Four: The material balance study

Step 10: Assembling unit process input and output information

The material balances were started by assembling the complete input and output data, converted to standard units, on the process flow diagrams (Figures 2-6).

Step 11: Deriving a preliminary material balance

From the collated information the preliminary balances were constructed for each processing area.

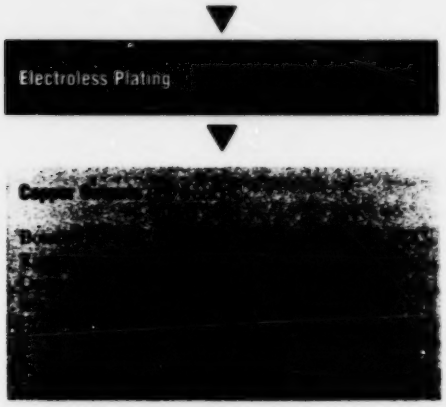
a) Sensitizing deburrer

The deburrer located in the sensitizing area is operated in a recycle mode (see Figure 2). Return water is continuously filtered to remove copper fines before being fed back to the deburrer. Captured copper fines are subsequently backwashed from the sand filter and collected in the bag filter. Essentially the copper inputs are from the brushed boards and the outputs are from the sand filter backwash bag filter and the cartridge filter. An accurate mass balance could not be constructed from the available information as the thickness of copper removed from the boards could not be determined precisely. However, Company A did plan to purchase a high resolution microscope in the near future which would enable accurate determination and control of copper thicknesses removed.

b) Sensitizing (Electroless Plating)

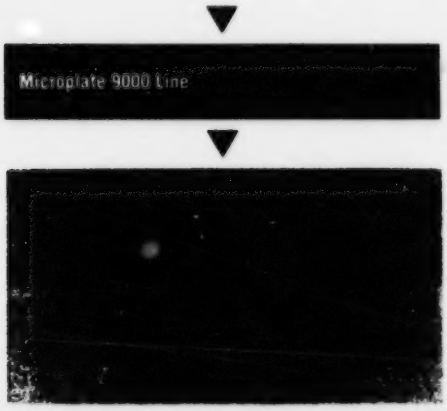
The preliminary material balance for the electroless plating line is shown below.

Copper inputs (kg/week)	
Copper fines from deburrer	0.040
Boards (microetch)	30.700
Etch solution	3.000
Electroless plating solution	25.000
Total	58.743



c) Electroplating Line (Microplate 9000 line)

Copper inputs (kg/week)	
Boards (microetch)	0.667
Boards (sulphuric/peroxide etch)	209.586
Copper anodes	124.500
Return etch solution	743.904
Total	1078.657

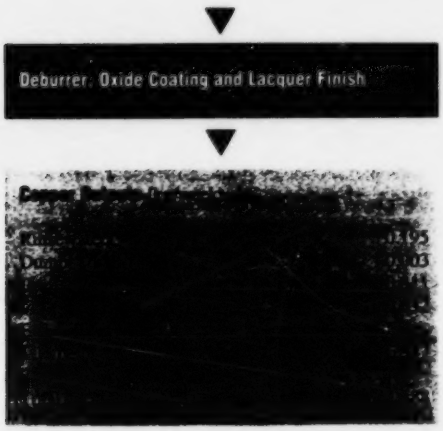


No make-up or dump of the sulphuric acid/peroxide etch tanks was made during the study period and as the crystallizer maintains a constant copper concentration in the etch tank these inputs and outputs were not considered in the material balance study.

d) Oxide coating area

Copper Inputs (kg/week)

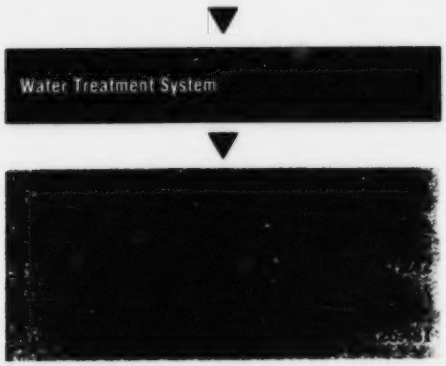
Boards (deburring)	0.653
Boards (microetches 10x10" inch)	0.825
Total	1.478



e) Water treatment

Copper Inputs (kg/week)

Pit 1 Influent	12.493
Pit 2 Influent	12.893
*Concentrated spent solutions	1.095
Total	26.481



*No concentrated copper solutions treated in the study period.

The volume of the filter press sludge was estimated by difference as the sludge was withdrawn from the clarifier on an irregular and infrequent basis.

In addition, a material balance was constructed from all the rinsewaters and daily dumps to the process drains and the feed to the wastewater treatment system over days 1-4. (This mass balance primarily represents the rinse waters as most of the dumps are done on day 5.)

Copper Inputs (kg)	
Rinses	
Sensitizing	
Alkaline cleaner rinse	0.014
Microetch rinse	4.404
Acid rinse	0.115
Electroless	0.259
Acid rinse	0.019
Electroplating Line	
Microetch	0.191
Floor capture	0.276
Electroplating	0.607
Etch rinse	0.600
Oxide Area	
Deburrer	0.653
Etch	0.025
Dumps	
Electroplating Line	
Microetch rinse	0.048
Electroplate rinse	0.235
Etch rinse	0.180
Total	8.346

Steps 12 and 13: Evaluating and refining the material balances

The material balances for the sensitizing and electroplating lines were considered to be very satisfactory and reflected well on the sampling and analytical study. In order to derive a preliminary material balance for the oxide coating area and water treatment area, a number of assumptions and estimates (by difference) had to be made. This led to good agreements but the estimates had to be backed up by further monitoring and information gathering.

The material balance for the copper inputs to the drains and the drain output to the wastewater treatment plant also showed a good agreement considering the complexity of the printed circuit board manufacturing plant and the large number of waste copper sources. Approximately 91 percent of the copper loading into the treatment plant during production days 1-4 was accounted for by the measured wastewater sources. The extra 9 percent was probably due to copper being washed from contaminated floor areas and further minor sources of copper which were not included in the survey (e.g. gold plating line). A decision was made to refine the material balance in an ongoing waste monitoring program.

A number of important conclusions could be drawn from the material balance information:

- The microetch rinse accounted for approximately 90 percent of the total sensitizing area copper loading.
- The microetch rinse accounted for approximately 56 percent of the plant's total rinsewater copper loading on the treatment plant.
- Other major sources of rinsewater contamination were the electroplating rinse, sulphuric/peroxide etch rinse and the deburrer (oxide area) rinse.

Phase Five: Waste reduction alternatives

Step 14: Obvious waste reduction measures

From the information accumulated from the waste audit and observations which were made while investigating the plant in detail a number of obvious waste reduction and efficiency improving measures were identified. These are again split into the four processing areas and the wastewater treatment plant.

a) Deburring operations (sensitizing area)
From the studies on the deburring, or surface conditioning operation, it was noted that the sand filter was backwashed with return (dirty) water which would lead to entrainment of copper fines throughout the sand bed. This could lead to fines being released into the filtered water. The debur-

red spray water had a suspended solids concentration of 104 mg/L. This high concentration probably accounted for the fine powder layer which was observed on the printed circuit boards after the deburrer drier. This represented an input of copper into the sensitizing line (0.04 kg/week).

The waste copper fines which were collected on the backwash bag filter system were shipped to secure landfill with the sludge cake from the filter press. However, the fines are relatively pure copper and investigations confirmed them to have a value of approximately $1.0/kg.

b) The sensitizing line (electroless plating)

As discussed previously, the results of the wastewater characterization showed that a very high copper loading was from the microetch rinse. This copper source represented 90 percent of the sensitizing rinsewater copper load. The sensitizing line is a manually operated plating line and it was observed that no drip time was used after the microetch. A one minute drip time was subsequently implemented and a monitoring programme initiated to record improved waste loadings. A static rinse drag-out tank could also be used to reduce the running rinsewater loading from this source.

c) Electroplating line

It was noted that the recirculation pumps on the copper electroplating line had leaking mechanical seals leading to copper crystallization on the pump shafts and surrounding floor areas. This copper material was subsequently picked up by the developer rinse, which flowed directly onto the floor, and discharged to the floor drain leading to Pit 1. The copper loading from this source at one floor drain close to the electroplate rinse was approximately 70 g/day. A satisfactory maintenance programme to prevent these leaks and installation of drip trays and general cleanliness in the copper electroplating areas could reduce this source of waste loading on the treatment plant. Good housekeeping in all copper processing and handling areas could prevent copper waste loading from other areas (e.g. the copper etch and crystallization) from reaching the drain system.

d) Oxide coating area

The rinsewater from the deburrer in the oxide coating area was discharged directly to the process drain. A bag filter was attached to the pipe at the outlet to the drain but during the in-plant study the capturing device was inefficient leading to significant quantities of copper fines being released to the drain system. Contact with acid wastewaters would subsequently dissolve the fines in the process drains. A closed loop filtration system similar to the one in the sensitizing area was added, eliminating this source of waste copper.

e) Wastewater treatment system

A number of inefficient operations in the wastewater treatment system were highlighted in the waste audit. First, alum was added to the pH corrected (pH 8.5) wastewater in Pit 1. Alum is an effective coagulant for

colloidal material but is not necessary for metal hydroxide precipitation and increases the volume of sludge produced.

Second, the existing sedimentation basin, a legacy from a former wastewater treatment system, was observed to be of inappropriate design suffering from inadequate sludge removal capability, accumulation of sludge and floating sludge creating effluent discharge problems.

Third, in an effort to overcome the periodic high levels of copper being discharged to the sanitary sewer, two sand filters were installed in parallel after the sedimentation tank. However, from the results in Figure 6 it can be seen that the sand filters were not effective in removing suspended solids or copper from the wastewater.

Assuming a 50 percent reduction of copper loading from the sensitizing microetch rinse through improved rinsing, and elimination of the copper loading from the deburrers and electroplating area floor drain, a 40 percent reduction in rinsewater loading to the wastewater treatment plant could be achieved.

Step 15: Targeting problem wastes

From Figure 6 it can be seen that the sand filter input concentrations of suspended solids and copper are approximately equal to the output concentrations from the filter. Furthermore, the copper discharged to the sanitary sewer was primarily dissolved (75-95 percent of total copper concentration) and in excess of the municipal by-law limits on days 2 and 5. Previous experience with the treatability of the printed circuit board wastewaters had established that the electroless copper wastewaters were particularly difficult to treat because of the presence of chelating agents in the electroless copper plating solution. In addition, chelating agents were present in the resist stripping solution. It was noted that when the treated resist strip was dumped to Pit 2 on days 2 and 4, significantly higher copper concentrations were observed in the sanitary sewer discharge than on days 1 and 3. Day 5 (Friday) represents an atypical waste treatment day as tanks in the sensitizing and oxide areas were dumped weekly on this day.

The chelate containing copper wastewater and combinations of copper and chelate containing wastewaters were therefore considered to be "problem wastes."

Treatability tests using alum, NaOH, lime and different flocculants were conducted on the pollutant sources individually and in combination. Table 1 shows the results of the treatability tests using lime for pH correction and 5 mg/L of an anionic flocculant. The tests indicated that most copper containing wastewaters could be treated very successfully by metal hydroxide precipitation. However, the chelating agents in the electroless rinse and resist strip rinse affected copper hydroxide precipitation and should therefore be segregated and treated separately.

The tests on the influent to the wastewater treatment plant indicated that

copper could be reduced from relatively high concentrations to less than the by-law limit (5 mg/L) using lime and an anionic flocculant. In general, lime produced a more dense and settleable precipitate than caustic although it generated more sludge material.

Table 1: Treatability tests using lime and anionic polymer

Sample	Raw/Treated	Total Copper in Supernatant (mg/L)
Sensitizing		
Microetch rinse	Raw	260.0
	Treated	0.3
Electroless rinse	Raw	9.1
	Treated	9.0
Electroplating Line		
Microetch rinse	Raw	22.0
	Treated	0.2
Copper electroplate rinse	Raw	33.0
	Treated	0.2
Copper electroplate rinse Resist strip rinse (50:50)	Raw	19.0
	Treated	20.0
Electroplate floor drain	Raw	44.0
	Treated	0.1
Sulphuric/peroxide etch rinse	Raw	40.0
	Treated	0.1
Oxide Coating		
Microetch rinse	Raw	150.0
	Treated	1.1
Wastewater Treatment		
Influent	Raw	11 74 13 73 8.4*
	Treated	0.4 0.6 0.4 4.0 0.7

*Hourly grab samples

Step 16: Developing long-term waste reduction alternatives

While the waste reduction alternatives described in Step 14 will reduce pollutant loadings and result in significant cost savings, an efficiently designed and operated end-of-pipe treatment system was still considered to be the best means of ensuring that Company A's effluent discharge limits would be met consistently. The following section describes the wastewater treatment and recovery system design which was developed, with the assistance of a consultant engineering company, from the waste audit and treatability studies. The major points for consideration in the system design were:

• Segregation of all the chelate-containing wastewaters from the conventional metal hydroxide precipitation system.

• Segregation and separate treatment/recovery of all the chelate-containing rinsewaters and concentrated bath-dumps.

• Collection of all general bath dumps (non-chelate containing) in a holding tank for metering back to the conventional treatment system at a controlled rate (to prevent surges in copper loading).

• Upgrading of existing pH adjustment, polymer addition, clarification and sand filtration systems for efficient metal hydroxide precipitation and subsequent discharge of high quality effluent.

The sources of chelate containing wastewaters were as follows:

Source	Flowrate (L/h) or Volume (L)	Copper Concentration (mg/L)
Mild Alkaline Cleaner Bath	400L	63.7
Mild Alkaline Cleaner Rinse	518 L/h	0.8 (maximum 1.7 mg/L)
Electroless Plating Bath	588 L	11000
Electroless Plating Bleed	10 L/h	11000
Electroless Plating Rinse	770 L/h	7.7 (maximum 10.3 mg/L)
Resist Strip Bath	920 L	less than 5.0
Resist Strip Rinse	390 L/h	-

Information on the type of chelator or chelate concentration was not readily available from the chemical suppliers.

The resist strip rinse and mild alkaline cleaner rinse waters both had copper concentrations well below the by-law limits and could therefore be discharged directly to sewer. The resist strip rinsewater, however, would require coarse filtration (cartridge filter) to capture occasional carryover of gross resist suspended solids. The resist strip bath dump also had a very low copper concentration but required batch treatment to remove resist material before discharge.

The remaining wastes, the electroless plating bath, electroless bleed, electroless rinse and mild alkaline cleaner bath all contained copper in excess of the by-law limits and required treatment/recovery. Current waste treatment and recovery technologies were reviewed. Available treatment

methods included sulphide and sodium borohydride precipitation. However, sulphide precipitation was not considered appropriate for the more concentrated solution and the sodium borohydride treatment, although effective, was costly and generated copper-containing sludge requiring subsequent disposal.

Recovery processes included electrolytic copper recovery and ion exchange. Ion exchange was not considered appropriate for the high concentrations in the spent plating baths and has not generally been applied to the recovery of chelated metals. However, electrolytic copper recovery, which is unaffected by the presence of chelates, has been used to recover copper efficiently from concentrated plating bath solutions down to 10 to 20 mg/L. The residual copper concentration would still be in excess of by-law limits and ion-exchange, using the new chelating type resins, could then be used to polish the wastewater prior to discharge directly to the sanitary sewer.

To reduce the volume of wastewater to be treated in the electrolytic recovery unit, a static drag-out rinse tank should be incorporated after the electroless plating tank and prior to the running rinse. The static drag-out tank would collect the majority of the copper drag-out load from the electroless plating tank and would then be dumped daily to the electrolytic unit for copper recovery. The subsequent running rinsewater would have a very low copper concentration and could be discharged directly to sewer (copper concentration now less than the by-law limit).

Efficient rinsing of plated products is a very important step in reducing rinsewater volumes and concentrations, and also in facilitating subsequent waste reuse and recovery. Figure 8 shows a general schematic diagram of a drag-out tank, counter-current rinsing, and associated waste recovery/recycling/treatment operations.

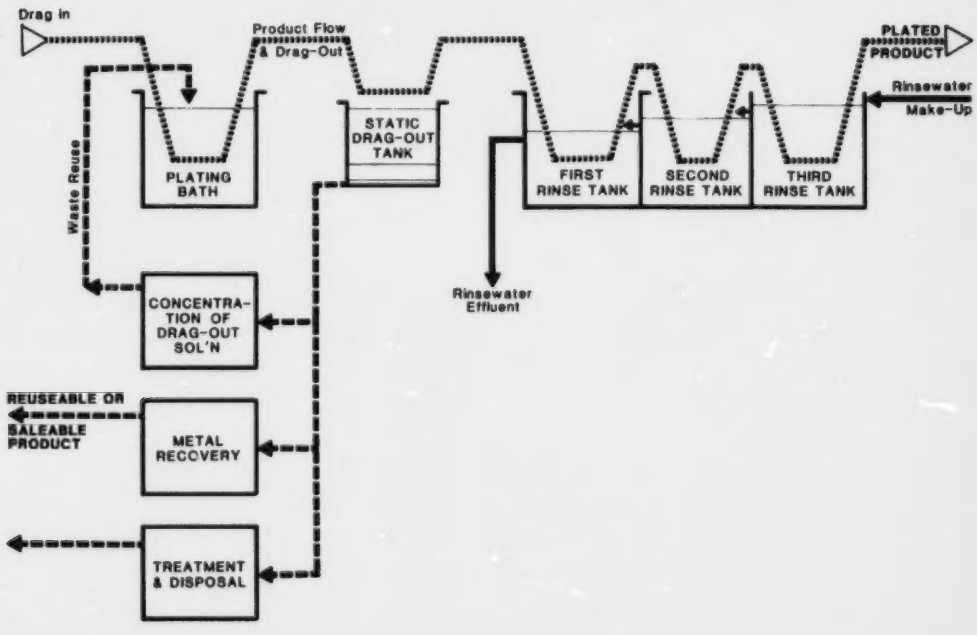


Figure 8: Drag-out tanks and countercurrent rinsing are used to reduce the total amount of water required to rinse the product and to concentrate the rinsewater for subsequent recovery.

Figure 9 shows the schematic process flow diagram for the waste segregation and wastewater treatment system. The treatment system incorporates the following key elements:

• Collection of all non-complexed rinsewaters in a common sump for pH adjustment with caustic (or lime) to pH 9.0-9.5.

• Installation of static rinse tank after the electroless copper plating bath. The static rinse tank will collect most of the drag-out loading from the electroless plating bath and will then be dumped daily for electrolytic recovery. The subsequent running rinsewater (chelate-containing) will then be discharged directly to the sanitary sewer.

• Segregation, cartridge filtration and direct discharge of resist strip rinsewaters (chelate-containing) to clarified water basin.

• Segregation and direct discharge of electroless plating running rinsewaters and cleaner rinsewaters (chelate-containing) to clarified water basin.

• Segregation and collection of resist strip and developer dumps (or bleed) in a separate holding tank for pH adjustment and direct discharge.

• Segregation and collection of electroless copper (chelate-containing) bath dumps, controlled bleed and drag-out tank contents together with alkaline cleaner (chelate-containing) and microetch (sensitizing) bath dumps in a separate batch recirculation tank for electrolytic copper recovery.

• Polishing of electrolytically treated solutions in a chelating ion exchange resin bed prior to discharge to clarified water basin.

• Segregation and collection of general bath dumps (e.g. microetches, predips, acids, alkalis, etc.) in a holding tank for subsequent metering into the pH adjustment sump.

• Modification of the existing sedimentation tank to incorporate a clarified water holding basin and provision for capture of accidental spills and emergency waste storage.

• Although it is considered that the effluent copper concentration from the proposed treatment system will comply with the existing by-law limit of 5 mg/L, it was recommended that Company A's sand filters be upgraded and included in the treatment scheme in anticipation of the proposed lowering of the by-law to 2 mg/L of copper. The clarified wastewater should be polished through a sand/anthracite dual media bed to increase the solids loading capacity of the filters.

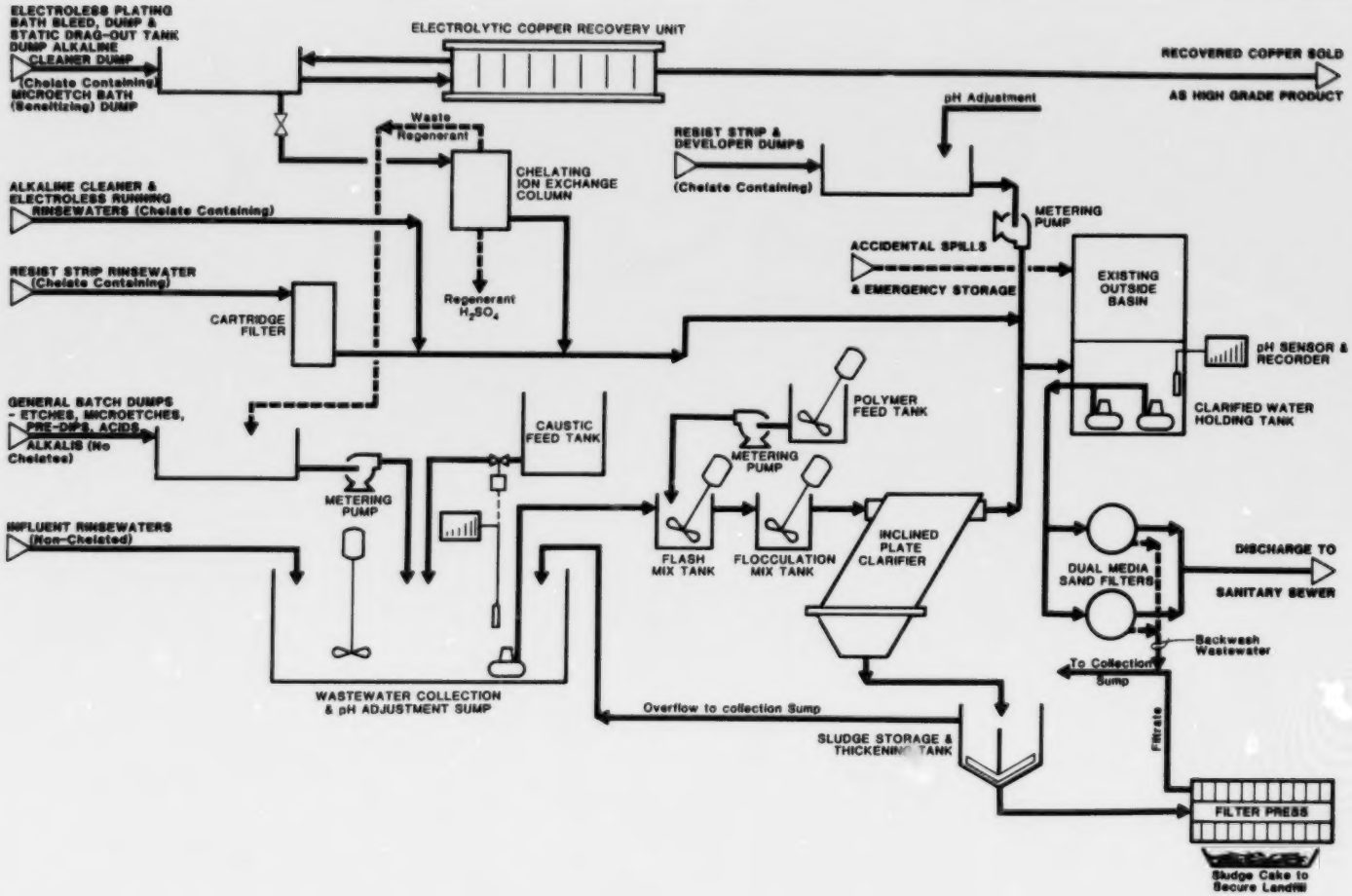

ELECTROLESS PLATING BATH BLEED, DUMP & STATIC DRAG-OUT TANK DUMP ALKALINE CLEANER DUMP (Chelate Containing) MICROETCH BATH (Sensitizing) DUMP
ELECTROLYTIC COPPER RECOVERY UNIT
RECOVERED COPPER SOLD AS HIGH GRADE PRODUCT
pH Adjustment
Waste Regenerant
CHELATING ION EXCHANGE COLUMN
RESIST STRIP & DEVELOPER DUMPS (Chelate Containing)
METERING PUMP
ALKALINE CLEANER & ELECTROLESS RUNNING RINSEWATERS (Chelate Containing)
ACCIDENTAL SPILLS & EMERGENCY STORAGE
EXISTING OUTSIDE BASIN
RESIST STRIP RINSEWATER (Chelate Containing)
CARTRIDGE FILTER
Regenerant H_2SO_4
pH SENSOR & RECORDER
CLARIFIED WATER HOLDING TANK
POLYMER FEED TANK
GENERAL BATCH DUMPS - ETCHES, MICROETCHES, PRE-DIPS, ACIDS, ALKALIS (No Chelates)
CAUSTIC FEED TANK
METERING PUMP
METERING PUMP
INFLUENT RINSEWATERS (Non-Chelated)
FLASH MIX TANK
FLOCCULATION MIX TANK
INCLINED PLATE CLARIFIER
DUAL MEDIA SAND FILTERS
DISCHARGE TO SANITARY SEWER
Backwash Wastewater
To Collection Sump
WASTEWATER COLLECTION & pH ADJUSTMENT SUMP
Overflow to collection Sump
SLUDGE STORAGE & THICKENING TANK
Filtrate
FILTER PRESS
Sludge Cake to Secure Landfill

Figure 9: Process design for Company A's waste segregation and wastewater treatment system

• The sludge from the inclined plate clarifier should be pumped to a sludge storage/thickening tank. Thickened sludge will then be periodically pumped from the storage tank for dewatering in the filter press. The reduced volume of sludge cake will then be disposed of in a secure landfill site.

Phase Six: Cost/benefit analysis and implementing action plan

Step 17: Doing a cost/benefit analysis for waste treatment/reduction

From the waste audit studies, the existing wastewater treatment system at Company A was found to be of poor fundamental design and a total upgrading of the treatment system was necessary. As Company A was facing legal action from the local municipality with respect to their violation of discharge standards, the return on investment was not of prime concern in this case study; of more importance was the development of the most cost-effective treatment/recovery system available.

From Step 16 a number of waste treatment recovery alternatives were identified and a process design subsequently derived on the basis of technical considerations. However, through the waste reduction opportunities described and the segregation and recovery of copper from the chelate-containing and microetch (sensitizing) wastes it was estimated that a cost saving of $25,000 per annum on sludge haulage and secure landfill disposal costs could be realized. In addition, it is estimated that approximately $4,000 per annum of copper could be recovered using the electrolytic recovery unit.

The total installed cost of the proposed system including the major equipment items (inclined-plate clarifier, sludge storage/thickening tank, filter press, electrolytic copper recovery unit, ion exchange unit) segregation pumping and piping, instrumentation and control and 40 m^2 building was $300,000. However, considering Company A's history of pollution problems, the impending legal action and the amount of time being spent by senior personnel on day to day waste management problems, the implementation of the waste segregation and treatment/recovery system could be considered money well spent and an investment for the future.

Step 18: Implementing your action plan: reducing wastes and increasing production efficiency

The results of the waste audit and the waste reduction/treatment studies were presented to Company A's management and plans were made to implement the recommended waste reduction measures and the treatment/recovery system.

The waste audit/reduction approach achieved the following objectives:

- Provided a sound understanding of all the sources of waste copper at the manufacturing plant.

- Identified and quantified the major sources of waste copper.

- Permitted evaluation of processing efficiencies from assembled information on unit processes, products, raw materials, water usage, and waste generation.

- Identified waste reduction opportunities.

- Eliminated some wastes and associated disposal problems.

- Identified "problem wastes" requiring special attention.

- Enabled the development of a cost-effective, integrated waste segregation and wastewater treatment/recovery system.

- Enabled the development of a waste management system which would comply with discharge regulations and result in improved public relations.

Case study 2: Steel pickling

Autonut Limited, a manufacturer of nuts and bolts for the automobile industry, purchases 25,000 tonnes of rod steel per annum from a local steel mill. However, during the manufacturing of steel, as well as during the storage and shipping of the rods to Autonut, the steel develops a surface coating of oxidized iron which must be removed before the steel can be drawn into wire for machining. This rust and scale is traditionally removed by chemically reacting the scale and steel with sulphuric (H_2SO_4) or hydrochloric (HC1) acid, a process called pickling.

In the pickling process, the steel is immersed in an acid bath which dissolves the scale and some of the iron. After a required period of time the steel is removed from the acid bath and the residual acid is rinsed from the steel. The steel then receives selected coatings and passes into the manufacturing plant. As the steel is being pickled, the iron content in the pickling acid bath increases, the pickling efficiency is reduced, and fresh acid must be added to the bath to maintain an efficient reaction rate.

Eventually, though, the iron content becomes excessive for effective pickling and the "spent pickle liquor" must be disposed of and replaced with fresh acid. The disposal of this spent pickle liquor and the pickling rinsewater creates a pollution problem and subsequent headaches for the manufacturer.

Autonut Ltd. installed a high speed sulphuric acid batch pickling facility some ten years ago which has operated very effectively ever since. However, since the plant was commissioned, environmental control regulations have tightened considerably. As a result, the company faces a confrontation with the authorities on air and water pollution problems resulting from acid fumes and periodic discharges of acidic rinsewater containing iron concentrations in excess of regional municipal by-laws. The concentrated acid waste has never been dumped down the sewer but tank-trucked away. The tank truck haulage companies have been increasing their rates by large amounts each year and the company now faces annual expenditures of about $350,000 for haulage and disposal.

Acid, water, electricity and labour costs are also increasing and the company wants to increase its production capability.

What is the best and most cost effective solution to these problems? The company started off on the right track by conducting an in-plant study or waste audit of its pickling and waste treatment operations. As you will see, the plant then adopted a waste reduction strategy and finally ended up *increasing* its production efficiency while simultaneously solving pollution problems resulting from fumes, water and waste acid.

The following case study describes the approach taken. To ensure the success of the studies, the Autonut management appointed a senior engineer to carry out and coordinate the waste audit and subsequent waste reduction plan. All employees were made aware of the importance of the work through newsletter bulletins.

Step 1: Listing of unit processes

The senior engineer started off the study by walking around the pickling and waste treatment facilities, listing all the unit processes and making notes on their function and use. He also solicited help from his foremen who were familiar with the day to day operations of the plants. The unit operations were listed in Table 1. Extensive notes on how the units were operated were also taken.

Table 1: Listing of Unit Processes

Unit Process	Functional Description
Pickle Tank (2x)	17.5 m^3, steel, rubber lined
High Pressure Spray Rinse Tank	30 spray rinse nozzles, supplied by 1000 L/min pump
Fume Scrubber	Packed bed wet scrubber with internal recycle
Lime Storage	Bulk quicklime storage (20 m^3)
Lime Slaker	to 30% lime hydrate
Lime Holding Tank	10 m^3
Neutralization Basin	Basin with rudimentary solids removal

In order to keep this case study concise and clear, only the essential operations, i.e. the pickling tanks, spray rinsing and wastewater treatment will be studied here in detail. However, detailed studies for other operations, e.g. surface coating and steam generation, could also pinpoint wastage and losses.

Step 2: Constructing a process flow diagram

A flow diagram was then prepared to illustrate the interrelationship of all the unit processes (Figure 1).

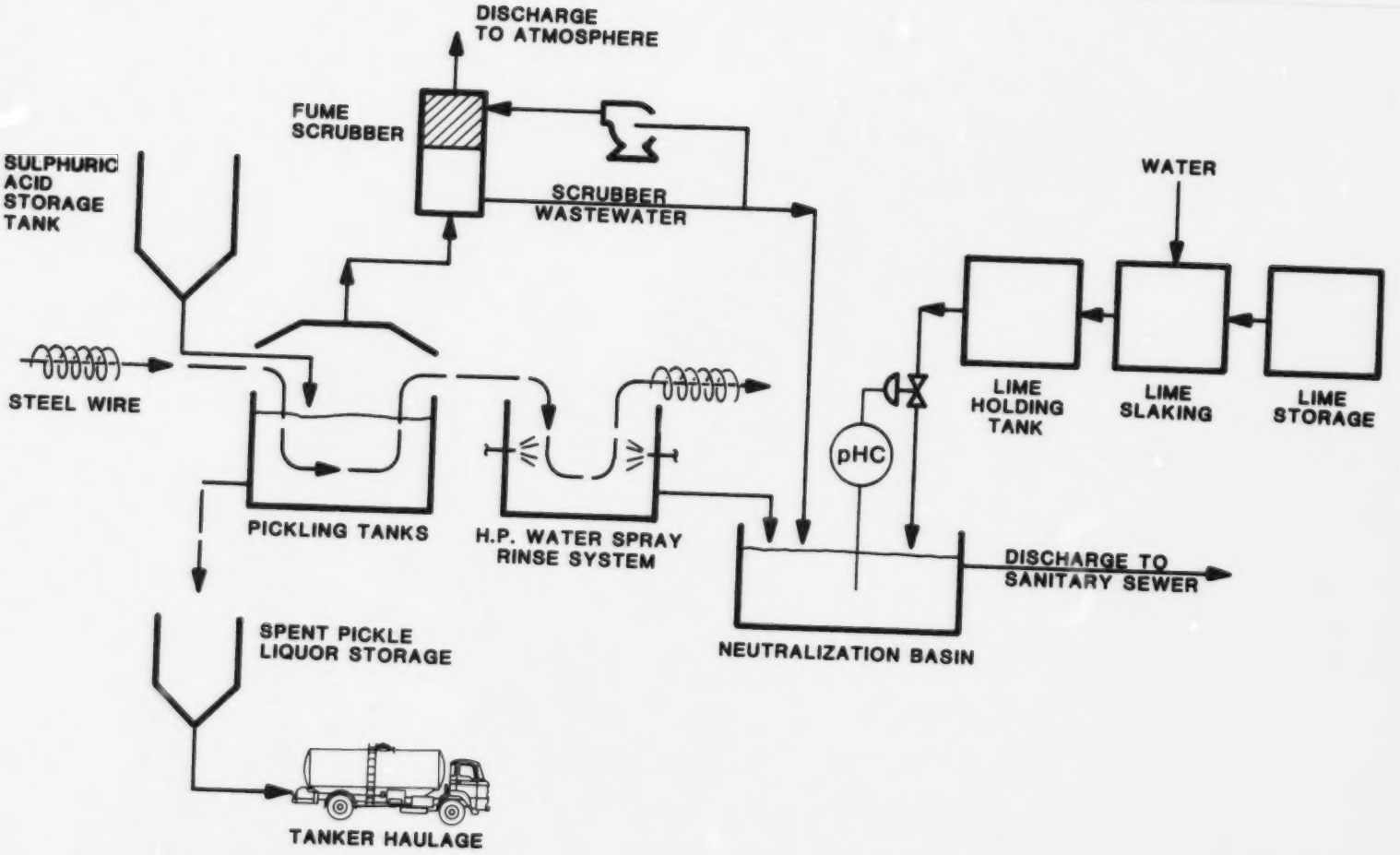


Figure 1: Schematic diagram of Autosteel's pickling and wastewater treatment processes

Step 3: Determining resource usage

The next step was to investigate the annual usage of raw materials from the company's purchasing records. The following information was obtained (Table 2):

Table 2: Annual usage of raw materials

Unit Process	Annual Raw Material Usage (tonnes)				
	Sulphuric Acid (93%)	Rod Steel	Steam (kJ/h)	Water	Lime (CaO)
Pickling Tanks	595	25,000	775,000	1,703	–
High Pressure Rinsing	–	–	–	24,300	–
Wastewater Pretreatment	–	–	–	2,600	590
Fume Scrubber	–	–	–	900	–

(All information was recorded in standard metric units)

Once all the unit processes were identified and described, supporting information on raw materials, handling losses, water usage and waste reuse was assembled as shown in Steps 4-6.

Annual expenditures for utilities were also recorded to be used later in the cost/benefit analysis (Step 17).

Step 4: Raw material storage and handling losses

Due to the nature of the two major raw materials, steel and sulphuric acid, it was considered that no significant handling losses were occurring. However, the company records for rod steel handling and acid consumption did seem to indicate that the type and time of rod steel storage might be having an effect on the actual pickling times required, probably due to increased scale formation. As pickling times can vary from 30 minutes to three hours, the engineer decided to investigate this at a later date.

Step 5: Recording water usage

The next step was to account for the water consumption at the pickling plant and determine what happened to the water. This is shown in Table 3. The total water consumption in the pickling plant was 338,800 m^3 per

annum. This water was used for all purposes at the plant including rinsing, steam production and tank make-up. Measurements of the spray rinsewater flows indicated that over two-thirds of the plant consumption was for rinsing only. The engineer looked at the spray rinse system and made a note that this was a definite area for waste reduction.

Table 3: Water Usage

Use	Quantity Used at Plant (L/d)	Quantity Sewered (L/d)
Pickling	5,670	0
Steam	5,300	0
Rinsing	81,000	81,000
Fume Scrubber	3,000	2,700
Wastewater Pretreatment	8,660	8,660
Others (make-up-washdown)	8,990	8,990

Note: The engineer recorded these figures in litres per day for comparative purposes but when he used figures for material balance calculations, all units were in m^3/annum (equivalent to tonnes/annum).

Step 6: Measuring current levels of waste reuse

It was noted that no wastes were reused at the pickling plant.

Steps 1 to 6 were concerned with the inputs to the pickling plant and wastewater treatment. Steps 7 to 9 are now concerned with defining the outputs from these operations.

Phase Three: Defining process outputs

Step 7: Identifying process outputs

The process outputs are listed in Table 4 below. Although only the pickling, spray rinse, fume scrubber and water treatment operations are considered here, this could be expanded to include other operations at a later date. Steps 8 and 9 illustrate how the process output information was categorized and tied down.

Table 4: Process outputs

Unit Process	Product	Waste Reused	Airborne Waste	Wastewater Sewered	Waste to be disposed of	
					Liquid Waste	Solid Waste
Pickling	De-scaled rod steel (24759)	–	Evaporation and acid fumes	–	Spent pickle liquor	Pickle liquor sludge
Spray Rinse	Cleaned rod steel	–	–	24,300	–	–
Scrubber	High pH waste-water to treatment	–	Evaporation	810	–	–
Wastewater Treatment	Dischargeable wastewater	–	–	29,890*	–	(small amount not quantified)

*Includes spray rinse wastewater. All figures in tonnes per annum.

The engineer noted a strong noxious smell from acid fumes while working around the pickling bath. The workers in the area said that it was not nearly as bad as it could be. He knew that this situation was unacceptable and noted the facts.

Furthermore, the engineer noted that the live steam injection (direct injection of steam into the pickling tank) which was being used for heating and agitating the pickling bath did not seem to be giving uniform and thorough agitation to the acid solution. He knew this could affect the efficiency of the pickling process.

Step 8: Accounting for wastewater flows

All wastewaters discharged to the sanitary sewer from the pickling and rinsing operations were pretreated for pH adjustment. Of the 29,890 m^3/annum discharged, 24,300 m^3/annum was from the rinsing operations. Apart from this being a heavy water usage, the tightening of environmental regulations was making it imperative that tighter control and modernization of the pH control be implemented. Historical analyses of the wastewater discharged to the sanitary sewer indicated that the pH of the effluent was subject to periods of overdosing and underdosing of lime.

Step 9: Documenting wastes stored and hauled off-site for disposal

According to waste disposal records, 2,191 tonnes of spent pickle liquor were hauled off-site each year at a cost of $350,000 p.a. The pickle liquor was hauled to a local oil recovery facility for disposal. In addition, when

the pickle tanks were dumped, considerable sludge (590 tonnes p.a.) was found in the bottom of the tanks. This sludge (ferrous sulphate) was shovelled into containers and dumped in a sludge disposal area, allowed to drain and hauled off-site by local contractors. The quantities of wastes hauled off-site to disposal are shown in Table 5.

Table 5: Quantities of wastes hauled off-site for disposal

	Wastes Hauled Off-Site for Disposal (tonnes)			
	Non-Registerable Wastes		Registerable Wastes	
Waste	Liquid	Solid	Liquid	Solid
Spent Pickle Liquor	–	–	2191	–
Waste Pickle Liquor Sludge	–	590	–	–

The engineer checked through the company manifest forms with respect to Regulation 309 of the Environmental Protection Act and agreed with the classification of the spent pickle liquor, which was regarded as a hazardous waste, having a waste classification number of 111C. The 'C' designation describes its primary characteristic as corrosive. No other liquid or solid wastes were registerable.

Phase Four: Material balance study

Step 10: Listing of process input and output information

Using the basic mass balance principle of "what goes in, must come out" the engineer then decided to list all the input and output information in order to determine the adequacy of the information he had already accumulated. He listed the information in Table 6.

Table 6: Process Inputs and Outputs

Pickling Process

Inputs	Quantity (t/a)
Steel	25,000
Acid (93% H_2SO_4)	595
Water (make-up)	1,702
Water (steam)	1,600
Outputs	**Quantity (t/a)**
Steel	24,750
Waste Pickle Liquor	2,191
Waste Pickle Liquor Sludge	590

Wastewater Pretreatment

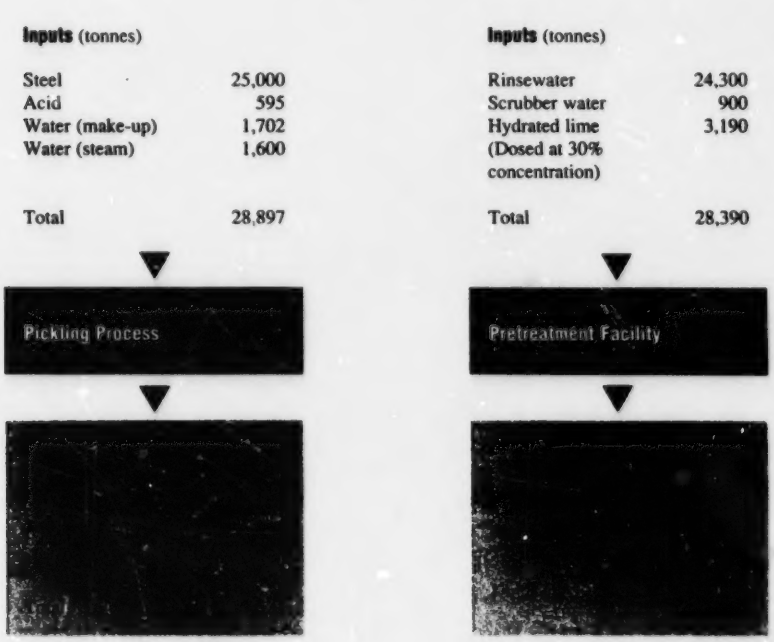
Inputs	Quantity (t/a)
Rinsewater	24,300
Scrubber Water	900
Hydrated Lime	3,190
Outputs	**Quantity (t/a)**
Discharge to Sanitary Sewer	29,890

All quantities in tonnes/annum.

Step 11: Deriving preliminary material balances

Preliminary material balances were then constructed for the pickling process and pretreatment facility as in Figure 2.

Figure 2: Preliminary material balances



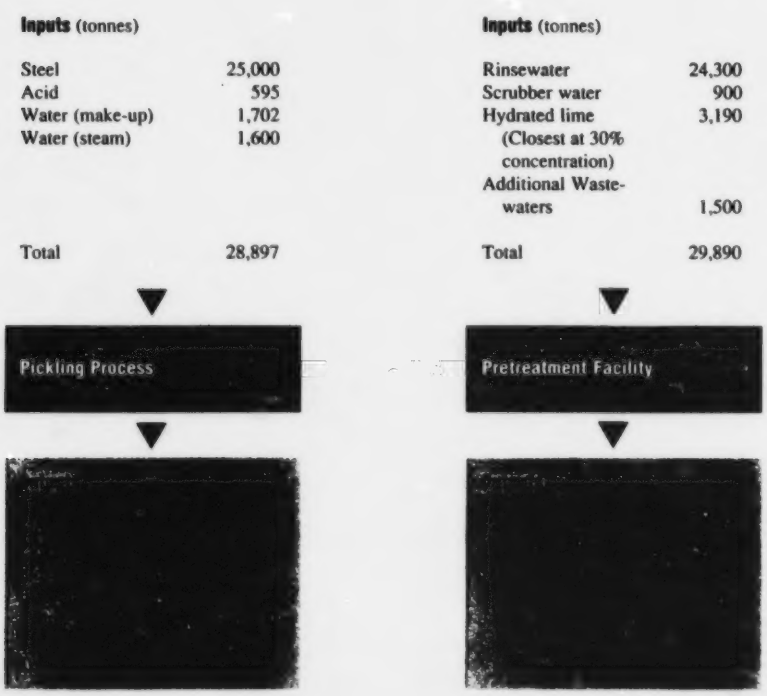
Step 12: Evaluation of material imbalances

From the pickling information available, a 1366 tonne output imbalance was obtained. However, the engineer knew that he had not considered the evaporation from the pickling bath nor the quantity of material dragged out from the pickling bath to the rinsing stage. Likewise, with the wastewater pretreatment, he had not considered some other streams which enter the facility from other sources (e.g. washing operations).

Step 13: Refining the material balance

The engineer calculated that the evaporation and dragout outputs amounted to approximately 1,400 tonnes per annum, thus affording an acceptable mass balance through the pickling process. He also conducted more "in-plant" measurements and accounted for an extra 1,500 tonnes of wastewater per annum entering the pretreatment facility from drag-out from the pickling process and clean-up operations. The refined material balances are shown in Figure 3.

Figure 3: Refined material balances



The engineer felt that he now had a very good understanding of the pickling process including its inputs, outputs, wastes and problems. He was also eager to implement measures to improve its operations and reduce the wastes being produced.

Step 14: Obvious waste reduction measures

From the information he had accumulated, the engineer could now pinpoint and quantify the major wastes generated from the pickling operation at Autonut Ltd. These were:

- waste pickle liquor
- waste pickle liquor sludge
- spray rinsewater
- pickling tank fumes

The waste pickle liquor and its associated sludge are an integral waste product from the existing pickling system. There were no obvious measures which could be applied to reduce or eliminate these wastes without significant process changes. However, the existing method of rinsing the rod steel using automatic high pressure sprays at about 1,000 litres per tonne of steel was an obvious source of unnecessary waste.

It was noted that a high level of pickling bath "drag-out" was occurring and also that the high pressure sprays were particularly inefficient with much of the rinsewater not even contacting the acid-covered rod steel. As a result, significant quantities of acid were being lost from the system and large quantities of acidic wastewater were requiring pH adjustment before discharge to the local city sewer system. The engineer considered this an obvious area for waste reduction.

While conducting his waste audit, the engineer had made use of a number of information services. He realized that the most common method for reducing excess rinsewater volumes is through "counter-current" contacting of the work and rinsewater. He also realized that one of the least expensive techniques of doing this for batch pickling was to use the dip and spray system; i.e. after dipping in the rinse tank, the wire is held over the tank and a spray of fresh water is activated and applied to the wire to remove the slightly contaminated rinsewater remaining on the steel. This slightly contaminated rinsewater then falls back into the rinse tank.

The engineer considered that he could reduce the rinsewater requirement from an inefficient 1,000 litres per tonne of steel to 100 litres per tonne of steel just by installing such a system. In this manner, very significant savings in rinsewater consumption could be achieved. Furthermore, the engineer recommended that instead of using live steam (direct injection) for heating and agitation, which condensed and introduced water to the pickling tank, an indirect steam heat exchanger should be used for heating and an air agitation system installed.

In this way, the pickling bath could have a negative water balance; that is, water would be lost from the pickling tank by evaporation instead of being introduced by the condensation of steam. As a result, the sulphuric

acid would not be diluted. In addition, the dilute acid solution from a counter-current rinsing system could be balanced with the evaporation rate and used as a make-up to the pickling tank, thereby reusing waste acid and completely cutting out the rinsewater discharge. The air agitation system would also increase pickling efficiency by improving mixing and accelerating the reaction rate, and would assist evaporation from the pickling tank.

With respect to the acid fume problems, the engineer recommended that a new and improved fume exhaust system be installed at the plant. He had discovered that an acid fume filter could be installed on the fume exhaust system. This synthetic fibre filter collects the acid mist and returns it to the pickle tank while releasing water vapour to the atmosphere. This was a vast improvement over the old wet scrubber system which produced large volumes of contaminated wastewater.

The engineer could therefore recommend modifications which would eliminate two sources of contaminated water, reduce the acid fumes in the work place and also recover sulphuric acid for reuse in the pickling tanks. Having found efficient ways to address the rinsewater and acid fume waste problems, the engineer moved on to Step 15.

Step 15: Targeting problem wastes

Step 14 lists the major wastes identified from the waste audit. The "problem" waste streams are the spent pickle liquor and the waste pickle liquor sludge. The spent pickle liquor is a hazardous waste with respect to Regulation 309 due to its corrosive nature and therefore disposal options are limited. The waste pickle liquor sludge is ferrous sulphate monohydrate—a potentially useful chemical with coagulant properties and with potential value for phosphorous removal applications at wastewater treatment plants.

The engineer decided to characterize these wastes and determine waste reduction/treatment options. The characterization results are shown in Table 7.

Table 7: Waste Characterization

Waste	Analysis	Annual Quantity Generated	Present Method of Disposal	Available Waste Reduction Treatment Technologies
Pickle liquor	4% H_2SO_4 10% Fe	2191 tonnes	Contract hauling of this hazardous waste	1. Acid Recovery
Pickle Liquor Sludge	$FeSO_4 H_2O$ (50% solids by weight)	590 tonnes	On-site drying followed by contract hauling of solids	2. Neutralization 3. Current Method of Contract Hauling

The engineer then proceeded to evaluate waste reduction and treatment options in Step 16.

Step 16: Developing long-term waste reduction alternatives

The engineer decided that three long term waste reduction/treatment alternatives were available to the company. These were:

Contract Disposal
This option would entail renewing contracts with haulage companies which find the most economical means for disposing of the hazardous spent pickle liquor. In Autonut's case, the haulage company had been transporting the spent pickle liquor to an oil recovery facility in Ontario. Autonut had to pay for haulage and treatment of the liquor.

Although no major investment costs would be incurred with this alternative, the Autonut management was hoping to become less dependent on haulage contractors and the spiralling disposal costs. Autonut would still have to upgrade its existing wastewater treatment facility.

Neutralization
In this option, the spent pickle liquor and rinsewaters would be neutralized with lime. This process would produce a calcium sulphate/iron hydroxide sludge which would require subsequent dewatering (by filter pressing) and disposal.

Acid Recovery
In the acid recovery process, the spent pickle liquor is pumped to a crystallizer where the iron salts are crystallized from the spent pickle liquor by cooling and the remaining acid solution is separated and made up to pickling strength with fresh acid. The net effect of the acid recovery system is to recover the untreated H_2SO_4 for reuse, instead of discharging it as a waste product.

In addition, ferrous sulphate crystals are generated and can be sold as a by-product. The price obtained for these crystals is very dependent on market conditions. Apart from the acid recovery equipment it would be necessary to a) balance water in/water out in the pickling tank through installation of indirect heating, air agitation and countercurrent rinsing systems and b) install an improved fume exhaust system with acid recovery (as described in Step 14).

As an engineer, the waste audit/reduction supervisor was impressed with the concept of zero discharge and the potential improvement in pickling efficiency (provided by air agitation and relatively constant sulphuric acid concentrations) with the acid recovery system. However, his recommendation had to be based on facts and cost-effectiveness and so he carried out the following cost/benefit analysis.

Step 17: Cost/benefit analysis of waste treatment/waste reduction

The engineer proceeded to compare the economics of the acid recovery and neutralization systems using the existing contract hauling alternative as a baseline. The results of the cost/benefit analysis are shown in Table 8.

Table 8: Comparison of economics forecast for treatment/reduction at Autonut Ltd.

	(All costs in thousands of dollars)			
Item	Basis	Acid Recovery	Neutralization	Current Method (Contract Hauling)
Capital Investment	25,000 tonne/yr. pickling plant	800	1200	–
Labour				
Operators	$25,000/man-year	25	25	12.5
Foreman	$30,000/man-year	3.0	7.5	0
Utilities				
Steam	$11/1000 kg	17.6		
Process Water	$0.35/m^3	(9.5)		
Electricity	$0.04/kWh	10.5		
Raw Materials				
H_2SO_4 (93%)	$110/tonne	(27.6)	–	–
CaO	$75/tonne	0	30.9	0
Shipping, Haulage & Disposal Costs				
Crystals ($FeSO_4$ $7H_2O$)	$17/tonne	20.9	0	0
Neutralization Sludge	$40/tonne	0	123	0
Pickle Liquor	$165/tonne	0	0	361
Pickle Liquor Sludge	$30/tonne	0	0	17.7
Maintenance				
6% Investment		48	72	
Wastewater Costs				
Sewer Fees	$0.35/m^3	0	10.5	10.5
pH Adjustment	$1.50/m^3	0	–	50.0
By-product Credit	$27/tonne	(33.2)	0	0
Total Annual Cost		54.7	268.9	451.7

Total Annual Cost Saving for Neutralization System	=	451,700 – 268,900	=	$182,800
Payback Time	=	CAPITAL COST / SAVINGS		
	=	1,200,000 / 182,800	=	6.6 yr
Total Annual Cost Saving for Acid Recovery System	=	451,700 – 54,700	=	$397,000
Payback Time	=	CAPITAL COST / SAVINGS		
	=	800,000 / 397,000	=	2.0 yr

Note 1: The engineer's calculations did not consider interest on investment, as he initially wanted to determine a straight-line payback period.

Note 2: The actual comparative payback time could be even less, as an upgraded wastewater pretreatment system would be required by the existing system anyway.

Note 3: Autonut was responsible for hauling the ferrous sulphate crystals ($FeSO_4.7H_2O$) to a chemical company ($17/tonne) and received payment for the crystals in return ($27/tonne).

Step 18: Implementing the action plan: reducing wastes and improving production efficiency

The engineer presented the results of his waste audit and the cost/benefit analysis of the waste reduction alternatives to a specially convened meeting of the Autonut management. It did not take long during the meeting to realize that they had been wasting valuable resources for years, and they agreed that by installing the acid recovery system they not only could save on raw materials but could totally eliminate waste and pollution problems. Furthermore, the pickling efficiency was expected to be improved by some 25 percent through better control of the pickling bath acid concentration and the improved agitation which would accommodate the company's plan to increase production.

Motivated by environmental and economic pressures, Autonut personnel came to realize that production efficiency, waste management and pollution concerns were interrelated. Through hard work and a deliberate waste audit/waste reduction approach, and by implementing their action plan, they succeeded in:

- improving process efficiency
- saving on raw materials
- eliminating waste and disposal problems
- improving the working environment
- improving relations with the regulatory authorities and local inhabitants

Because of the benefits gained through conducting a waste audit on the pickling process, the company proceeded to conduct a similar study in the manufacturing plant.

Case study 3: Detergent manufacturing

Sud Chemical is a detergent manufacturing facility in a popular resort area of Ontario. It produces a large number of intermediate and final detergent based products which are generally manufactured by batch processing in response to customer demand. The plant's processes, therefore, involve frequent changeovers from one product to another which result in significant quantities of wastewater being generated from process equipment cleaning operations.

Overall, the plant produces a relatively low volume, concentrated and complex wastewater which used to be discharged directly to a small lake popular for recreational activities. However, two years ago, in response to complaints from cottage owners and pressure from the Ministry of the Environment (MOE), Sud Chemical installed a concrete aeration basin to pretreat the wastewater before discharge to the lake. Unfortunately, the aeration basin did not perform up to expectations and very low organic removals were achieved, particularly in the winter months. Consequently the MOE issued a final control order on Sud Chemical, giving it a limited period of time to clean up the wastewater or face plant closure.

Sud Chemical was unsure how to approach its problem. Various alternatives had been proposed by different companies to improve the wastewater treatment system but Sud Chemical was not convinced these systems were adequate and the projected costs were considered to be far too high. Having established that the "end-of-pipe" wastewater treatment option was prohibitively expensive, Sud Chemical management decided to move back up the pipe and see if waste reduction at source could be implemented. The plant chemist contacted OWMC for advice.

Since the plant chemist was the person most familiar with all the chemical processing operations and the water usage at the plant, he was designated as the waste audit supervisor. The following case study describes the waste audit/waste reduction approach taken.

Phase One: Defining process inputs

Step 1: Listing of unit processes

The plant chemist started off his waste audit by identifying the major unit processes at his plant and then proceeded to accumulate as much information as he could about them. He found that he was collecting so much information that he opened a file for each process. The processes were listed as in Table 1.

Table 1: Major Plant Processes and Brief Functional Description

Unit Process	Brief Functional Description	File No.
Alkylphenol synthesis	Alkylation of phenol for external sales and as intermediate for production of wetting agents	1
Non-ionic detergent synthesis	Ethoxylation of alkylphenol to make industrial wetting agents	2
Amide synthesis	Reaction of fatty acids and fatty amines with ethanolamines to make amide type foam stabilizers	3
Sulphonated anionic detergent synthesis	Sulphonation of alkylated benzenes to make linear alkyl benzene sulphonates (LAS)	4
Cationic detergent synthesis	Reaction of tertiary amines with methyl chloride to produce a quaternary ammonium chloride (for fabric softening)	5
Detergent formulation	Blending of tertiary chemicals to produce final detergent products	6

Step 2: Constructing a process flow diagram

A schematic flow diagram was then prepared to show the inter-relationship of the process (Figure 1).

Once all the unit processes were identified and described, the plant chemist proceeded to assemble information on raw materials, handling losses, water usage and waste reuse as shown in the following Steps 3 to 6.

Because of the complexity of Sud Chemical's processes and the large number of unit processes involved, only the alkylphenol production process will be described in detail in the waste audit section (Phases 1 to 4) of this case study. The waste reduction strategy is then discussed for the whole plant in Phases 4 and 5.

Phase Two: Defining process inputs

Step 3: Determining annual raw material usage

The plant chemist then began sifting through the company's accounting and purchasing records to determine the precise quantities of utilities, chemicals and supplies purchased. This aspect of the work also became a good check on measurements taken in the plant. The following information (Table 2) on raw material usage was obtained for the alkylphenol production process.

Figure 1: Schematic flow diagram of Sud Chemical's process

Table 2: Raw Material Usage

	Annual Raw Material Usage (tonnes)		
Unit Process	Alkenes	Phenol	Catalyst
Alkene storage tank	1400	–	–
Phenol storage tank	–	1000	–
Alkylation reaction vessel	1400	1000	2.4
Distillation	–	–	–

He was unable to obtain information on water usage from the purchasing records as all the water used for the cleaning and cooling processes was obtained directly from the lake. He determined the water usage through field measurements described in Step 5.

Step 4: Investigating raw material storage and handling losses

Due to the large number of raw materials used at Sud Chemical the plant chemist spent a long time accounting for the raw material storage and handling practices at the plant. His thoroughness was rewarded, though, and he was able to identify a number of losses which occurred through the plant. He noted down his observations and the reasons why losses were occurring.

In the alkylphenol production process, for example, he found that a significant quantity of phenol (±3%) was lost as a vapour from the phenol storage tank vent and immediately recommended that a condenser system be installed.

Step 5: Recording water usage

The next step was to account for the water usage at the plant and determine what happened to the water. The plant chemist had no idea of how much water was being used in alkylphenol production and therefore decided to quantify its use. The washing frequency was directly related to changeover from one product to another. The plant chemist accurately recorded the product type and water usage over a two month period.

He determined that the still was washed out approximately once every week and that 7000 litres of water were used per clean out. He extrapolated this result to determine the annual water usage. The alkylation reaction vessel was washed infrequently and after speaking to his foreman he found out that it was cleaned out every six months with 8000 litres of water. He confirmed this by measurements in the plant.

The water consumption for the alkylphenol production process is shown below (Table 3).

Table 3: Water usage in alkylphenol production

Water Use	Quantity Used Per Annum (m^3)	Quantity of Wastewater Discharged to Treatment Per Annum (m^3)
Alkylation Reaction Vessel Cleaning	16	16
Still Cleaning	350	350
Alkylation Reaction Cooling	2700	–
Still Condenser Cooling	2300	–

All the water used at the plant was obtained directly from the lake. Although no accurate consumption figures were available, the plant chemist estimated that a total of 1700 m^3 of water were used at the plant each day. He based his estimate on pumping records, pump data and a pumping test. Most of the water was returned directly to the lake although 250 m^3 per day of contaminated water was passed for treatment in the aeration basin.

While accounting for water usages the plant chemist realized that the vast majority of the wastewater was generated from the washing and cleaning processes and he made a note that this was an area for waste reduction.

Step 6: Measuring current levels of waste reuse

Some wastes were reused at the plant. In the alkylphenol production process unreacted phenol was stripped from the residue, in a distillation stage, for reuse back to the phenol storage tank. The plant chemist took measurements and estimated that 500 tonnes of phenol per annum were reused.

Phase Three: Defining process outputs

Step 7: Listing process outputs

The plant chemist listed the process outputs from the alkylphenol production process as below (Table 4).

Table 4: Process outputs

Unit Process	Product	Waste Reused	Airborne Waste	Liquid Waste	Solid Waste
Phenol Storage Tank	–	–	Vapour loss through vent	–	–
Alkylation Reaction	Alkylphenol/ plant & excess phenol (2900 tonnes)	–	–	washwater –	spent catalyst
Distillation	Alkylphenol (2400 tonnes)	Phenol (500 tonnes)	–	washwater still bottom	–

He then proceeded to quantify these outputs in Steps 8 to 10.

Step 8: Accounting for wastewater flows

The plant chemist had determined the annual water usage in the alkylphenol production process in Step 5 and was therefore able to complete Table 5 as follows:

Table 5: Wastewater flows

	Discharge to		
	Treatment Plant		Lake
Source	Flow (m^3/annum)	Concentration BOD (mg/L)	Flow m^3/annum
Reaction Vessel Cleaning	366	2100	–
Cooling	–	–	5000

All plant wastewaters from the process equipment washing operations were collected in a common subsurface drainage system and passed to the aeration basin before discharge to the lake. The plant chemist sketched out the drainage system and identified the major wastewater points of entry. He was concerned that no facility existed to divert or hold any spills or leaks and noted this in his records. The plant chemist estimated the wastewater flow to the aeration basin to be 74,000 m^3 per annum. He estimated that 450,000 m^3 of cooling water and uncontaminated process wastes were returned directly to the lake each year.

Step 9: Documenting wastes stored and hauled off-site for disposal

According to the company's waste disposal records, 3000 kg of spent catalyst and 8000 kg of still bottoms were hauled off-site each year. The spent catalyst and still bottoms are both regarded as hazardous wastes under Regulation 309 of the Environmental Protection Act.

Step 10: Listing of process input and output information

The plant chemist then began listing all the input and output information (Table 6) in order to conduct a material balance and to determine if there were any obvious information gaps.

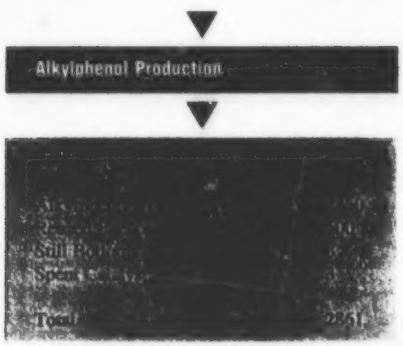
Table 6: Process inputs and outputs

Alkylphenol Production Process	
Inputs	**Annual Quantity (tonnes)**
Alkenes	1400
Phenol	1000
Reused Phenol	500
Catalyst	2.4
Cooling Water	9000
Wash Water	366
Outputs	**Annual Quantity (tonnes)**
Alkylphenol	2350
Reused Phenol	500
Still Bottoms	500
Spent Catalyst	3
Cooling Wastewater	9000
Wash Wastewater	366

Step 11: Deriving a preliminary material balance

A preliminary material balance was then constructed for the alkylphenol production process as in Figure 2. Cooling water and wash water were not considered in the mass balance as these inputs were assumed to equal the wastewater outputs. However, the quantities of organic material which were discharged in the wastewaters were subsequently estimated from measurements of chemical oxygen demand.

Figure 2: Preliminary material balance



Step 12: Evaluation of the material imbalance

The plant chemist was confident that he had an adequate material balance for the alkylphenol production process. Furthermore, he estimated from the wastewater analyses that approximately 70 kg per annum of alkyl phenol was lost in the wastewater.

Step 13: Refining the material balance

The plant chemist developed the waste audit and material balances for all his unit processes. When he had finished he felt much more knowledgeable about his plant, its inputs, outputs, wastes and problems. By making critical observations and taking notes while he was conducting the waste audit he had also identified a number of waste reduction opportunities.

Phase Five: Waste reduction alternative

Step 14: Obvious waste reduction measures

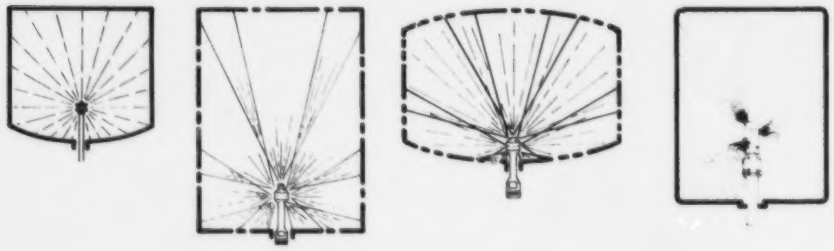
During his audit, the plant chemist had measured wastewater flows and had also taken numerous samples for analyses. This information not only helped to refine his material balance but also helped to identify the major sources of pollution. The information he collected indicated that process equipment washwaters were by far the biggest source of wastewater and product loss in all the processing areas. Furthermore, as he had gone around the plant he had been making critical observations and he considered that the washout procedures, which he had taken for granted for years, were extremely wasteful.

The washout procedures involved filling the reaction vessels with water, cleaning with detergent, and then rinsing. The plant chemist decided to conduct some washout tests at the plant laboratory. He performed these tests with the object of producing a low volume concentrated washwater for potential reuse and for minimizing the total washwater volume. He found that by diverting the initial high concentration washwater to a holding tank he could prevent the bulk of the contaminants from entering the wastewater. Furthermore, product formulation tests indicated that product quality was not impaired when high concentration wastewater was blended back into production.

This was just the start of a concerted effort to reduce the volume and concentration of the wastewater requiring treatment. The following procedures were also implemented:

• Ball washers were installed to increase the efficiency of vessel washouts. Ball washers are spraying devices which give a powerful and thorough wetting of tank and vessel walls to provide effective cleanouts. A variety

of ball washer systems are available for different sizes and shapes of vessels (see below).



• The plant chemist initiated improved product scheduling to minimize changeovers and corresponding required cleanouts. For example, the product formulation tank cleanout frequency was reduced from five to two times per week by better scheduling. Larger storage tanks were also installed to increase the length of production campaigns, further decreasing the number of cleanouts required. He also started to dedicate some tanks to specific products.

• Special washwater tanks were set up to hold wastewaters for subsequent use in detergent formulation.

• Tanks were either bought or modified to facilitate easy and efficient washout and drainage, i.e. tanks were made to pitch, had rounded bottoms, were elevated from the floor and sloped to the exit valve.

• Simple leaks and dripping valves were repaired, packing glands on pumps were replaced by mechanical seals wherever possible and a new maintenance programme was initiated to keep equipment in good repair.

• Level controls and, in some cases, larger tanks were installed to prevent overflows.

• Monitoring of specific wastewaters was stepped up with the installation of good quality flow measuring equipment and increased sampling and analysis.

• Modifications were made to the wastewater drainage system to enable spills and leaks to be diverted and stored if necessary. In this way shock loadings of contaminants were prevented from disrupting the treatment system and causing environmental pollution.

• Probably as important as the practical waste reduction measures was the change in attitude of all employees towards the generation of waste, prevention of spills and water use. An education program was organized by the plant chemist which helped to make all employees waste prevention conscious.

Everyone attended a series of talks entitled "Washing profits down the drain" which used photographic slides to show wasteful and poor processing techniques and improved practices resulting in waste prevention. An employee suggestion program gave financial bonuses for ideas which resulted in improved efficiency and waste reduction.

As a result of these efforts, the wastewater volume from the treatment facility was reduced by 40 percent (from 250 m^3/day to 150 m^3/day) and the total contaminant loading of the plant's wastewater (as measured by the chemical oxygen demand) was reduced by 50 percent.

Step 15: Targeting problem waste streams

The management at Sud Chemical was very pleased with the results of the waste reduction program. However, the MOE, although equally impressed with the improvements made, was still unhappy about the contaminant loadings being discharged into the lake. The MOE maintained that its control order stipulation for discharge of 15 mg/L biochemical oxygen demand, 15 mg/L suspended solids and 0.5 mg/L total phosphorus must be met. Having reduced their waste output considerably, the Sud Chemical management targeted their efforts to treating the reduced total plant wastewater stream.

The plant chemist decided to characterize his total plant wastewater and conducted an extended sampling programme. The average results are shown in Table 7.

Table 7: Characteristics of Total Plant Wastewater

Parameter	Average Wastewater Concentration (mg/L)
Flow (m^3/d)	150 (m^3/d)
BOD	2400
pH	9 (pH units)
Suspended Solids	150
Total Phosphorus	3
Phenol	50

The high BOD (biochemical oxygen demand) indicated that a biological treatment process was required. But the presence of poorly biodegradable materials was of concern. The plant chemist proceeded to investigate wastewater treatment options in Step 16.

Step 16: Developing long-term waste reduction alternatives

The plant chemist decided to recommend that Sud Chemical employ a consulting engineering company in order to determine the best alternatives for the wastewater treatment system. He was satisfied that he had implemented good sound measures based on his waste audit to significantly reduce waste, but now realized that the upgrading of the wastewater

treatment facility required specific expertise and engineering skills. The management of Sud Chemical agreed with the plant chemist's recommendation and an engineering company was retained to upgrade the treatment facility.

The upgraded system involved converting the existing aeration basin to an activated sludge treatment system with a secondary clarifier and associated sludge return pumping and pipework. Design points of particular interest included a floating cover and steam injection for temperature control during winter operation, addition of readily degradable substrate (methanol) to assist overall biodegradation (obtained by storing plant wastewaters) and addition of alum to assist secondary clarification and phosphorus removal.

Phase Six: Cost benefit analysis

Step 17: Waste treatment cost benefit analysis

Sud Chemical was placed in a position of having to upgrade its wastewater treatment system in order to comply with a control order from the MOE. However, the cost of the upgrade system, based on the existing wastewater flow, was prohibitively expensive (approximately $1 million). In Sud Chemical's case, significantly reducing waste was the only practical waste management approach to take. By moving back up the pipe and conducting a waste audit on its processes, Sud Chemical was able to identify, segregate, and in some cases reuse its waste washwaters to achieve significant waste reduction.

The total cost of implementing the waste reduction measures described in Step 14 was approximately $50,000. Sud Chemical estimated that the savings made in reducing raw material use amounted to $20,000 per annum. This represents a straight line payback of investment of 2.5 years. More important, however, the waste reduction policy significantly reduced the wastewater flow rate so that the existing aeration basin could be modified to an activated sludge system and the associated clarifier and equipment could be sized at approximately half the level required for the old flowrate. In this respect the total cost for the wastewater treatment plant upgrading of $500,000 represented a very significant saving compared to earlier cost estimates.

The waste audit approach, and subsequent waste reduction, almost certainly saved Sud Chemical from closing down. The plant is now thriving and production has increased by 25 percent. Not only has Sud Chemical managed to reduce water usage, raw material usage and waste loads but it also improved public relations and profits as well.

Chapter 4: Resources and information

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List of Ministry of the Environment Offices in Ontario

Regional Offices

London: 985 Adelaide Street West, London N6E 1V3 (519) 621-2200
Hamilton: 119 King Street West, 12th Floor, P.O. Box 2112, Hamilton L8N 3Z9 (416) 521-7640
Toronto: 7 Overlea Blvd., 4th Floor, Toronto M4H 1A8 (416) 424-3000
Kingston: P.O. Box 820, 133 Dalton Street, Kingston K7L 4X6 (613) 549-4000
Sudbury: 199 Larch Street, Sudbury P3E 5P9 (705) 675-4501
Thunder Bay: P.O. Box 5000, 435 James Street South, Thunder Bay P7C 5G6 (807) 475-1205

District Offices

Windsor: 250 Windsor Avenue, 6th Floor, Windsor N9V 6V9 (519) 254-2546
Sarnia: 265 N. Front Street, Suite 109, Sarnia N7T 7X1 (519) 366-4030
Owen Sound: 1180-20th Street, Owen Sound N4K 6H6 (519) 371-2901
Clinton: c/o Min. Ag. & Food, P.O. Box 688, Clinton N0M 2L0 (519) 482-3428
Welland: 537-642 Niagara Street North, Welland L3C 1L9 (416) 384-9896
Cambridge: 400 Clyde Road, P.O. Box 219, Cambridge N1R 5T8 (519) 653-1511
Halton-Peel: 1226 White Oaks Blvd., Oakville L5H 3B9 (416) 844-5747
Barrie: 12 Fairview Road, Barrie L4N 4P3 (705) 726-1730
Muskoka-Haliburton: Gravenhurst P0C 1G0 (705) 687-3408
Peterborough: 139 George Street North, Peterborough K9J 3G6 (705) 743-2972
Belleville: 15 Victoria Avenue, Belleville K8N 1Z5 (613) 962-9208
Ottawa: 2378 Holly Lane, Suite 204, Ottawa K1V 7P1 (613) 521-3450
Pembroke: P.O. Box 67, 1000 MacKay Street, Pembroke K8A 6X1 (613) 732-3643
Cornwall: 4 Montreal Road, 2nd Floor, Cornwall K6H 1B1 (613) 933-7402
Sault Ste. Marie: 445 Albert Street East, Sault Ste. Marie (705) 949-4640
Timmins: 83 Algonquin Blvd. West, Timmins L4N 2R4 (705) 268-3222
North Bay: 1500 Fisher Street, Northgate Plaza, North Bay P1B 2H3 (705) 476-1001
Parry Sound: 74 Church Street, Parry Sound P2A 1Z1 (705) 746-2139
Kenora: P.O. Box 5750, 808 Robertson Street, Kenora P9N 1X9 (807) 468-5578

Government funding

The following is not intended as a comprehensive listing of programs for which government funding is available. Contact your local offices of MOE and Environment Canada for further information.

Federal Waste/Energy Reduction

Development and Demonstration of Resource and Energy Conservation Technology (DRECT) Program
Environment Canada is funding a program to stimulate energy-efficient new technology applied to a solid, liquid or gaseous waste stream. If a company wants to design and install a new, unique pollution control technology, Environment Canada may contribute up to 50 percent of the costs under its DRECT program. Some research and development work may be included – bench and pilot scale – but it must be tied to the installation of a prototype process operating in the marketplace. For further assistance call the DRECT Program coordinator at: (819) 953-1192 or write to:
DRECT Secretariat
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

Industry Energy Research and Development Program (IERD)
This federal energy conservation program will contribute up to 50 percent of the total estimated cost of an approved project. It is aimed at promoting the development of projects, processes, or systems that will increase the efficiency of energy use throughout industry, and at encouraging use of the technology developed under the program. For further information contact:
IERD Secretariat
Department of Energy, Mines and Resources
580 Booth Street
Ottawa, Ontario
K1A 0E4
Tel: (613) 996-2480

St. Lawrence River Environmental Technology Development Program.
Projects must involve the development and application of new or improved technologies for use by industry. They must have a direct impact on the St. Lawrence River and limit or eliminate industrial pollution. For further information contact:

ETDP National Coordination Office
Industry, Science and Technology Canada
235 Queen Street
Ottawa, Ontario
K1A 0M5
(613)954-3225

Business Information Centre (BIC).
The Business Information Centre within the Federal Business Development Bank helps business people seeking information about federal government programs and services. It can provide assistance in the form of grants, loans, loan guarantees and repayable contributions. For further information call: 1-800-268-9103

Ontario Assistance Programs

Ontario Development Corporation (ODC)
The ODC provides financial assistance to secondary manufacturing companies which cannot obtain adequate funding elsewhere to purchase pollution control and energy saving equipment. For further information contact:
Ontario Development Corporation
5th Floor, 56 Wellesley Street West
Toronto, Ontario
M7A 2E7
Tel: (416) 965-4622

Comprehensive Funding For Waste Management (4 R's) Projects
In June 1987, the Ontario Government announced a new comprehensive funding program for waste management. The new program will provide industries and municipalities with financial assistance for reduction, reuse, recycling and recovery of wastes (the 4 R's). Assistance to industries may be in the form of grants, technical advice and information.

Eligible projects include:
- Feasibility studies
- Reduction, reuse, recycling, or recovery of wastes
- Process or equipment modification or evaluation
- Demonstration of technology
- Upgrading existing operations beyond current state-of-the-art for a particular industry
- Research

Eligible Costs:
- Capital costs – up to a maximum of 50 per cent of the total eligible cost
- Start-up (commissioning) costs – up to a maximum of 50 per cent
- Demonstration/evaluation of technology/process – up to 100 per cent of a proponent's eligible costs for a defined time period necessary to demonstrate/evaluate the proposal
- Research – up to 100 per cent of proponent's eligible costs.

For further information contact:
Ministry of the Environment, Waste Management Branch, Industrial Program Unit, (416) 323-5200.
Ministry of the Environment Regional Offices:
Kingston (613) 549-4000
London (519) 661-2200
Sudbury (705) 675-4501
Thunder Bay (807) 475-1205
Hamilton (416) 521-7640
Toronto (416) 424-3000

Selected Reading List

Profit from Pollution Prevention – A Guide to Industrial Waste
Campbell M.E., Glenn W.R., 1982
Pollution Probe Foundation, Toronto, Ontario
The best way to get rid of a barrel of industrial waste is to recycle it into production, or not to generate it in the first instance. In this book, Pollution Probe researchers address the problems inherent in the production, use and disposal of hazardous chemicals.

Rationale for the Selection of Technologies for Treatment and Disposal of Special Wastes in Ontario
Status Report to the Ontario Waste Management Corporation, 1985, Toronto, Ontario
This source explores options for the disposal of wastes which remain after processing.

Proven Profits From Pollution Prevention – Case Studies in Resource Conservation and Waste Reduction
Huisingh D., Martin L., Hilger H., and Seldman N. Institute for Local Self-Reliance, 1986, Washington, D.C.
The case studies in this manual demonstrate that efficient management of industrial wastes at individual plants is a major part of the remedy for the current hazardous waste problem.

Technical Manual Waste Abatement, Reuse, Recycle and Reduction Opportunities in Industry
By Resource Integration Systems, Proctor and Redfern Group, Ontario Research Foundation, Environment Canada, J.L. Richards and Associates Ltd., Published in 1983 by Environment Canada. Available from Environment Canada, 25 St. Clair Avenue East, 7th Floor, Toronto, Ontario M4T 1M2.
Deals with plant processes, waste generation and waste characteristics and identifies opportunities for solid and liquid waste abatement, reuse, recycling and recovery. Case studies of successful industrial resource recovery are presented. This manual addresses waste reduction opportunities in the following sectors: inorganic chemical production, metal finishing, primary metals production and fabrication, primary textiles manufacturing and organic chemical production.

Status of Ontario, Regulation 309 (under the Environmental Protection Act). Revised Regulation of Ontario, 1980 as amended to Ontario Regulation 322/85, June 1985.
Regulation 309 is one of the most stringent pertaining to the transportation, handling and storage/disposal of potentially hazardous wastes. All those involved with wastes covered by this regulation should be aware of its provisions.

Science and Engineering for Pollution-Free Systems
By David Krofchak and J. Neil Stone
One of the first books written specifically about waste reduction. Considerable detail is given to the treatment of pickle liquors. Published in 1975 by Ann Arbor, Science Publishers Inc., P.O. Box 1425, Ann Arbor, Michigan 48106.

Cutting Chemical Wastes
By David Sarokin, Warren Muir, Catherine Miller, Sebastian Sperber.
This book takes a close look at what 29 organic chemical plants are doing to reduce hazardous wastes. It also reviews the factors influencing waste reduction practices at these plants. Published in 1985 by Inform Inc., 281 Park Avenue South, New York, N.Y. 10016.

Low or Non-Pollution Technology Through Pollution Prevention
Prepared by 3M Company for the United Nations Environment Program, Office of Industry and Environment.
Copies of this publication are available from Henry G. Owen, Senior Public Relations Specialist, 3M, P.O. Box 33600, St. Paul, Minnesota 55133.

Technical Reference Material on Waste Reduction and Treatment Technologies - a service to industry provided by OWMC.

Ontario Waste Management Corporation (OWMC) has an ongoing program to help Ontario industry reduce its wastes. As part of this program, it will help you locate literature on waste reduction, reuse and recycling processes. The ORTECH International library is also available to Ontario industry. For further information contact:

Waste Reduction Group
Ontario Waste Management Corporation
2 Bloor St. West, 11th Floor
Toronto, Ontario
M4W 3E2
(416)923-2918
1-800-268-1179

ORTECH International
2395 Speakman Drive
Mississauga, Ontario
(416)822-4111

On-Site: Technical Assistance for Waste Generators

On-Site is a project to help Ontario manufacturers improve their waste management procedures. It is sponsored and managed by Energy Pathways Inc. (EPI), an Ottawa-based consulting company. Through On-Site, unemployed engineers and technicians are being placed in many companies for 6-month work terms to carry out waste management-related activities. During this time, their salaries and benefits are paid through the Unemployment Insurance Section 25 Job Creation Program.

On-Site employees are analyzing waste streams, costing out treatment systems, instituting process changes, reducing quantities of wastes produced and setting up administrative systems to deal with new requirements arising from Regulation 309 and the Transport of Dangerous Goods Act. The companies involved include manufacturers of chemicals, paints and coatings, textile manufacturers, food and beverage processors and metal finishers.
Any Ontario manufacturer needing waste management assistance can apply to On-Site. EPI will help develop job descriptions, screen candidates and handle administration. The employer carries out the interviews and hiring, determines the project workers' duties and provides day-to-day supervision. Workers are covered by Workers' Compensation and third party liability insurance.

On-Site
2652A Danforth Ave., 2nd Floor
Toronto, Ontario
M4C 1L7
(416)690-7226

Canadian Waste Materials Exchange (CWME).

Find users for your wastes by checking through the bimonthly Bulletin published by the Canadian Waste Materials Exchange. This program, operated by ORTECH International, has been in existence since 1978. Annual subscriptions to the bulletin are $50.00. For more information contact:

Canadian Waste Materials Exchange
ORTECH International
2395 Speakman Drive
Mississauga, Ontario
L5K 1B3
(416)822-4111 ext. 358

Ontario Waste Exchange

A project of OWMC, the Ontario Ministry of the Environment and ORTECH International, the Ontario Waste Exchange (OWE) helps industries minimize their waste generation and find uses and users for their special wastes. Established in 1984, the OWE is fully funded by MOE and OWMC. For more information contact the Ontario Waste Exchange at:

ORTECH International
2395 Speakman Drive
Mississauga, Ontario
L5K 1B3
(416)822-4111 ext. 512

Regional Waste Exchanges

It is worthwhile contacting the public works department of your regional government to inquire if there is a regional waste exchange listing wanted and generated wastes. Some waste exchanges publish a bulletin for industries in their region. Regional exchanges only pass on inquiries to advertisers. They are not involved in transactions or negotiations and company names are kept confidential.

Region of Durham	(416)668-7721
Essex/Windsor	(519)776-6441
Guelph	(519)837-5604
Region of Halton	(416)827-2151
Region of Haldimand-Norfolk	(519)587-4911
Region of Hamilton-Wentworth	(416)526-2671
Lindsay	(705)324-2712
London	(519)661-5411
North Simcoe	(705)526-0625
Ottawa	(613)564-1147
Region of Peel	(416)566-1511
Peterborough	(705)742-7771
Stratford	(519)271-0250
Metro Toronto	(416)392-4200
Region of Waterloo	(519)885-9426
Wellington County	(519)843-4173
Ontario Recycling Information	(416)960-0938 or 1-800-263-2849